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ABACUS.

The abacus, or instrument for counting, has been developed into many commercially useful forms, the more prominent of which are, mechanical devices, such as fare-counters, for checking the receipt of numerous small sums of money, revolution and speed counters necessitated by the present extended use of machinery, and the slide rule.

Fare-Counters.—The introduction of street tramway systems has given impetus to inventive ideas as to methods of checking the amounts of the fares received by the conductor. Many of these inventions are merely duplications of former ideas; the illustrations in the subsequent descriptions are therefore to be considered typical. Following the division laid down in the article on this subject contained in the first division of this Dictionary, the various typical inventions may be considered under the heads of *Counters*, *Recording Counters*, with *Check Systems*. The last head scarcely includes methods sufficiently related to Engineering to call for description in this work, and these may be but shortly dealt with.

Check Systems.—Check systems include the use of coupons, whether these are tickets numbered consecutively, or counterdiscs variously engraved, or balls of different diameters. One of the simplest check systems is that introduced by J. Haworth, in 1867, the conductor being provided with a box containing coils of tickets consecutively numbered, each ticket being torn off when paid for, or issued to the passenger. Longer and shorter distances, to which correspond different fares, require a separate coil for each difference in fare. This system is the simplest mechanical extension of the counterfoil check, which leaves a foil in a ticket-book for every ticket issued to a passenger. A modification of this plan was introduced by J. H. Betterley and W. Davidson, in 1874, who devised that by the depression of a lever, a certain length of chemically prepared paper should be thrown forward from a box containing the roll. The paper being prepared with nitrate of silver, or otherwise made sensitive to the action of light, became discoloured and could not be again used; the length of the paper strip checked the amount of fares received. An improvement upon this roll-ticket system was invented in 1873, by J. T. Parlour, who attached to the spindle of the paper-roll suitable gearing in connection with an indicating or registering apparatus.

Another species of check system is that in which counter-tickets variously engraved with the different distances or fares are employed, or instead of engraved tickets, tickets or balls of different sizes are used. Sometimes these representations of fares paid are dropped into a proper receiving chamber by the passenger, or by the conductor in presence of the passenger. The modifications of this principle are very numerous, but none appear to have received general application, for which the reasons are sufficiently obvious. Analogous to this system is that of so-called safety fare-boxes, which are money-boxes with different compartments and openings for the receipt of the proper fares to be introduced by the passengers. In some cases these boxes have been provided with apparatus to indicate whether the box has been inverted, for the purpose of abstracting money. An improvement on the foregoing principles was instituted by H. A. Walker, in 1872, in which the checks are enclosed in a tube or chamber, a handle drawn forward by the money-taker brings out the bottom check, and the number of checks issued is indicated on a counting apparatus. An improvement on the fare-box principle was introduced in 1877 in England, as the invention of G. Beadle, of America; in this the money or ticket dropped into the box is stopped in its passage by a slide, the withdrawal of which causes an alarm to sound and actuates a register.

Other check systems have for their representative the way-bill, or paper form on which the conductor scores within the passenger's view the amount and number of fares he has received. To prevent fraud by the obliteration of these entries, a device was introduced in 1877, by Kennedy and Anderson. which consisted in placing the way-bill between two perforated hinged slabs of wood or iron, the way-bill being perforated to correspond with the perforations against which the price is marked, in the slabs, as the fares are paid.

Simple Fare Counters or *Indicators.*—The earlier inventions for checking the amount of fare paid, or to be paid, appear chiefly to be intended for application to cabs, either to inform the hirer how much he ought to pay, or the distance he has traversed, or to inform the proprietors the distance the cab has run under hire during the day, and the amount due to them for fares. For these purposes, A. Sutton, in 1862, devised an indicator with double set of index-hands, and a divided dial in gearing with the wheels of the cab. The mechanism, of the ordinary character obtaining in indicators driven by gearing, and consisting of a suitable train of wheels, is contained in a box or case mounted upon a shaft, so as to be capable of being turned to show the words Hired or For Hire. In the position when the word Hired is shown, the train of the indicator is thrown into gearing, and the distance traversed by the wheel recorded; bringing the words For Hire into view, causes the indicator to be thrown out of action. As the passenger would desire to know the distance travelled, his interference would be sufficient guarantee to the proprietor that

37151

the cab had not run whilst the words For Hire were shown. This invention may be taken as the type of a considerable number of devices for the same purpose. But for the purposes of indicating the number of persons entering vehicles, such as omnibuses and tram-cars containing more than one fare, some modification becomes necessary, as the end required is not only the distance travelled, but also to know the number of travellers. There appear three principles underlying the inventions for this purpose, that is, the inventor has availed himself of the use of a turnstile at the entrance or exit, or at both, or of the use of a movable step, which, in connection with certain gearing recorded the act of stepping into and from the vehicle, or of a seat arranged so that the weight of the passenger should cause a record. In a few inventions these three principles are combined. The other methods devised leave greater reliance to be placed upon the conductor's performance of his duty, and as they are somewhat various are better separately described.

In 1873, M. A. Weir introduced the use of a turnstile, a cam on the shaft of which communicates pressure to a bellows, and thus, by tubing, pneumatically conveys to a dial impulses, registering the number of turns caused by the entrances and exits of passengers. The indicator-dials are as numerous as there may be stations or differences of fare, and changes are effected by a worm-wheel in gearing with the wheels of the vehicle, so that shortly before arriving at a given station or distance, the proper dial is brought into play. In the case of tramways a rise or projection in the road causes this change of indicator. In 1874, J. Robertson devised the improvement of a movable step, placed at such a height that the passenger is compelled to step upon it when entering or leaving the vehicle. By a simple shaft and mechanism, the depression of the step or platform is communicated to a dial, upon which is indicated the number of depressions. As, however, indication upon a dial would be obviously inferior to a graphic or printed record, most inventors have turned their attention to the construction of permanently recording instruments, and these will be found described under the head of registering or recording counters.

Counters actuated by the conductor or person in charge of the vehicle, may be represented by the invention of W. Thomas in 1867, in which an operating handle is placed at any convenient part of the omnibus, preferably at the back near to the step on which the conductor stands. From this handle motion is conveyed by rods to the registering apparatus, the indicating dials of which are placed in view of the passengers, and to a signal bell or gong. The operating handle is fitted in a slot, and is pushed or made to slide to one end to register one; a spring or balance weight is provided to bring it back into position for the next movement. The motion being conveyed to the registering apparatus by shafting, a trigger or trip-piece there sounds a bell. This trigger takes into the teeth of a wheel on a shaft, and causes both it and the shaft to make one-tenth of a complete revolution. This shaft is in the centre of the registering apparatus, and is fitted with a ratchet wheel in which a pawl falls to prevent it from moving backwards. A disc on which numerals are formed, is also secured on the shaft, and moves with it, so that each successive figure is made to move round opposite to a glazed opening large enough to allow only one figure to be seen at a time. In 1869, H. Grothe introduced a more complicated system of levers and dials, to indicate the changes arising from difference in fares.

Registering, or Recording, Fare-Counters.—In 1862, W. J. Curtis devised a cab-register, which includes a packet of cards having printed on them a graduated dial. Each passenger receives a card, which is placed upon a revolving table in the recording apparatus in connection with the wheels of the cab. Upon starting the card is punched, and upon removing it, it is again punched, and the distance between the two nicks shows the distance travelled. The punch in the second nicking strikes out the centre of the card and discharges this into a receiver. This punched-out portion bears a counterpart of the nicks on the portion retained by the passenger, and therefore shows the amount of the fare chargeable to the passenger. In 1863, P. Gaskell invented a system in which motion is also taken from the wheels of the cab, to a toothed wheel turning freely on an axis, which passes through the centre of a dial-plate, and has attached a hand or pointer. This axis carries at its other extremity a small punch, which is presented to a disc of paper corresponding to the dial-face. The punch pierces the paper at starting and stopping of the vehicle; and a radial movement given to the punch prevents its piercing the disc twice in the same place. In 1867, W. Cooke devised a system, utilizing the three chief operating means or agents, the motion of the vehicle itself, the weight of each passenger when seated, and the weight of each passenger whilst passing on to, or off from the vehicle. Motion is taken from the hub of the wheel, or from any other rotating part, and conveyed to a drum or roller. This drum or roller gives motion to a band of paper, on which the diagram or register is to be made by a number of pencils, one of which is in communication with each seat. When a passenger sits down, the seat is depressed, and the motion communicated to the pencil to make or break contact of the pencil with the paper, and so make a line, either during the time the passenger is seated, or when the seat is unoccupied. In detail, the cushions of the seats are made air-tight, and each one is placed in communication with a small closed inflatable ball, placed near the drum and paper. When a passenger sits down, the cushion of the seat occupied is compressed, and the air forced therefrom into the ball or vessel, which is expanded; this raises the pencil, which is balanced on a fixed joint, from contact with the paper, and so leaves the paper in blank as long as the seat is occupied. The moment the seat is vacated, contact takes place, and a line or mark is made as long as the vehicle continues in motion. To provide a check, so as to show that contact was made or broken by a new passenger, and not simply by the same passenger rising up and sitting down again, a movable step is constructed on to which every passenger must tread on mounting, or leaving, the vehicle. The motion of the step is consequently compressed in, and transmitted by a cord, or other means, to produce on the paper a mark, or leave a blank. If at the time contact of the pencil and the paper is made or broken, there is a mark or blank made or left by the moving of the seat, it is clear the passenger has left the vehicle, even if the diagram shows that the seat was taken immediately after being vacated. In 1875, J. T. King added to this system a method of interlocking the movable seats, so that the seats sat upon caused the unoccupied seats to rise; and further recorded by a type-printer, upon a paper ribbon or strip, the number of the seat occupied. In 1877, C. F. Hayes introduced the use of a turnstile which, by gearing, communicates motion to two circular tables furnished with graduated indicator cards, one card indicating entrances, and the other exits. A travelling marker is fitted above each card, and moves inwards radially a short distance, as the vehicle is performing its journey, and when given distances are accomplished returning to its normal position. This return of the marker to its normal position, indicates commencement of a fresh section of the journey and increment of fare.

It is worthy of notice, that notwithstanding the mechanical ingenuity displayed in these inventions, none seemed to have surmounted the practical difficulties sufficiently to have come into general use.

Portable Fare-Counters.—The mechanical attachments to vehicles being cumbersome and expensive, several inventors have sought to introduce recording ticket-punches, that either by a register, or by a store of punched-out pieces, may serve to check the amount of fares received. In 1873, N. Macphail introduced a hand apparatus, including a small bell and printing mechanism, in which the bell was to be sounded once for every penny paid. This idea received great improvement in 1874 in an invention introduced from America, where it had been extensively used. As its use in this country has been somewhat general on the tramway systems, the punch is described in detail.

In Fig. 1, A is the upper, and B the lower handle of the instrument, hinged together and provided with an ordinary punch-tool. C is the case containing the bell and register mechanism, on opposite sides of a partition. There are covers to this case. Register wheels are actuated by a stepped pawl, attached to the radial arm swinging on the arbor of the register wheels, and connected with a projecting portion of the web of the upper handle A by a projecting pin. The pawl moves the register one degree each time the handles of the punch are closed.

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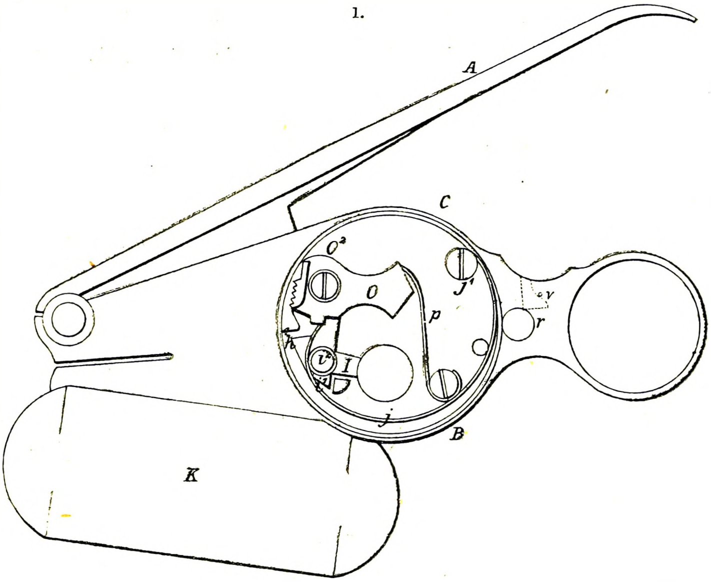

The general construction and operation of the register mechanism is as follows—

The bell is secured to a stud on the inner side of the cover, and I is the arm of the bell-hammer pivoted to the case C. The arm is provided with two secondary arms i^1, arranged at right angles to the former, above and below its fulcrum i^2; j is a curved flat spring, secured to the case C at j', and bearing with its free end against the upper arm of the bell-hammer, so as to hold the latter closed; a cam is mounted loosely on the pivot i^2 of the bell-hammer, between the arm I of the latter, and the partition of the case C; it is provided with a tooth h^1, projecting under the portion of the upper handle A, and a smaller projection or tooth, arranged in rear of the tooth h^1, while it carries on the opposite side of the pivot i^2, a shoulder engaged under the arm I of the bell-hammer, in the angle formed by the arm i^1 with the arm I.

In closing the handles of the punch, the portion of the upper handle strikes the tooth h^1 of the cam, turning the latter on its pivot i^2, and raising the hammer against the spring j, by means of the shoulder engaging under the arm I. When the movement of the handles is completed and the bell-hammer released, the latter and the cam are returned to their former position by the spring j, and the bell is rung. In opening the handles, the end of the portion of the web comes in contact with the tooth h^1 of the cam, and turns the latter slightly on its pivot, the shoulder having a little play in the angle of the arms I and i^1, to permit the cam to be so turned back. The punch being in position of Fig. 1, with the handles distended, the spring p, bearing against the upper incline of the detent pawl, holds the lower tooth o^1 of the latter against the lower and upwardly inclined ratchet.

In closing the handles in operating the punch, the detent pawl O slides over the ratchets until it comes in contact with the cam-tooth, which turns the pawl O on its pivot until the spring p, which has pressed against the upper inclined side of the pawl, passes the apex, and engages against the lower incline, when the pawl O is shifted, so as to engage its upper tooth O^2 with the upper series of ratchets. During the closing movement of the handles, the detent pawl O, being in contact with the lower series of ratchets, prevents any retrograde movement of the handles, until the closing movement is nearly completed, and the register moved one degree, when the pawl is shifted as described, so as to clear the lower ratchet and prevent the handles opening. Hence an attempt to ring the bell without operating the register, by partially closing the handles and then suddenly releasing them, will be unsuccessful.

During the last portion of the closing movement of the handles, the portion of the web is disengaged from the bell-hammer and the bell rung, the register having been moved one degree, and locked by the respective detent pawl, a little before the bell is rung. In opening the handles, the pawl O slides over the upper series of ratchets, and prevents in a similar manner the closing until the handles are almost completely opened. This prevents the ringing of the bell by opening the handles to such a degree as to engage the hammer-pawl with the bell-hammer, but not sufficiently to cause the register-actuating pawl to engage over the next notch of the register wheel. During the last portion of the opening movement, the cam-tooth comes in contact with the upper tooth O^2 of the pawl O, and shifts the pawl to its natural position, leaving the punch free for a second operation. During the shifting of the pawl O, a tooth comes in contact with the tooth of the cam, so that the cam, which has been slightly turned back during the opening of the handles, will be returned to its former position, with the tooth h^1 projecting under the portion of the upper handle, ready for a second closing of the handles.

K is the receptacle for the punch cuttings, secured to the underside of the jaw B of the punch; it is of cylindrical or other suitable shape, and provided with a single aperture in its side adjacent to the jaw B.

When the person using the punch obtains access to the registering mechanism, by picking the lock, and sets the hands back to the starting-point, for the purpose of retaining the number of fares, which he cancels during the movement of the registering mechanism from the point on which it has been so placed to the starting-point, the fraud is exposed by the wheel remaining stationary at the last notch before reaching the starting-point, thus indicating that the full number of fares which the apparatus is capable of registering has been cancelled, while a lesser number of fares is returned.

A modification of this invention was devised in 1874 by T. B. Doolittle, in which a semi-cylindrical barrel or tube contains a series of ratchet wheels having numbers on their faces, and a vertically moving spring bar or rod, provided at its upper end with a spring hook or catch, which when the punch-bar is depressed takes hold of the first of a train of wheels, and turns the same one point at each stroke. The rod at the lower end is provided with another spring catch, for the purpose of operating a small striking hammer, so as to sound an alarm bell.

Revolution and Speed Counters.—It is frequently of the highest importance that the speed or number of revolutions in a given time, of an engine or other machinery should be known or ascertainable with accuracy. In marine engines this is especially desirable, as well as in certain kinds of mills where uniform speed is a necessity. For almost all descriptions of work, there is a certain speed at which the working results are highest, and it becomes important to the manufacturer to maintain the speed, in order to avoid excess of wear and tear on the one hand, and secure a full return of work on the other. Although desirable in some cases, it is not necessary in all that the machine should record or register, and generally it is sufficient that the machine should show at a glance the rate of speed at that particular moment. It is almost universally the practice, to count the speed or number of revolutions of an engine at so many in the minute, and this, if an ordinary counter were employed, giving merely the number of revolutions made since a certain starting time, would necessitate reference to a clock or other mode of marking time. But in speed-counters generally, the practical difficulties that such a time-keeper would introduce, are obviated by the adoption of the principle of centrifugal force, as illustrated in the use of governor-balls. A counter or indicator on this plan was introduced by Sir D. L. Salomons in 1874, and is shown in Fig. 2, in which *a a* are the spindle and sleeve of an ordinary governor, connected to the

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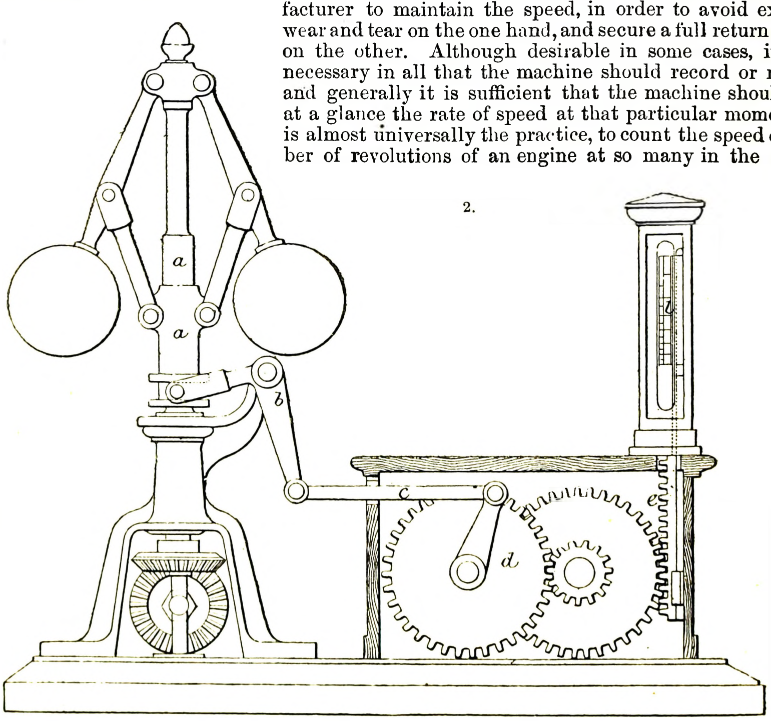

wheel *d* by the crank and rod *b* and *c*, which impart motion to the rack *e*, carrying a pointer; and this indicates the speed on the scale *l*. Such a machine indicates speeds not affected by any great variation with sufficient accuracy, but is not adapted to cases of fluctuation from low to high speeds. The same inventor also introduced three other forms of indicator. One of these was a kind of fan-blast, the pressure of air caused by the fan moving a piston against a spring, a pointer attached to the piston indicating the speed on a scale, the divisions of which must be found by previous experiment. In another form, based on this principle, a curved, flattened tube, like an aneroid tube, is substituted for the piston and spring, the tube in uncoiling from the pressure of air within it actuating a crank and pointer. In a third form, Salomons causes a tube to rotate horizontally about the centre of its length, a small pipe from each end of the tube leading to a glass tube placed in combination with a vertical spindle. The tube being filled with mercury, is caused to rise by centrifugal force in this central tube, and the height of the mercury indicates the speed. M. A. Weir introduced in the same year a modification of this centrifugal principle, employing a vertical glass tube filled with liquid revolving on its longitudinal axis, the depression of the centre and rise of this liquid against the sides of the tube, indicating the speed on a scale parallel to the tube. R. H. Crickmer in 1874 devised an indicator which also controlled the action of the throttle-valve. In gearing with the machinery, the speed of which is to be measured, is a vertical cylinder. revolving on its longitudinal axis within an outer fixed cylindrical case, between which and the inner cylinder is a small annular space. The inner cylinder is continued at its lower end into a flat hollow wheel, and the outer case conforms to this wheel; the wheel is also perforated, so that by centrifugal force, mercury contained in the cylinder is forced up through the perforations in the wheel into the outer cylinder, according to the speed. Upon the surface of the mercury in the cylinder floats a hollow iron ball, which follows the movements of the surface of the mercury. Attached to the ball is a vertical shaft in connection with suitable gearing, causing a pointer to move over a dial, and working the throttle-valve by means of a rack and segmental lever.

Fig. 3 is of a direct comparison counter, which consists in combining a wheel, rotated at regular intervals by a clockwork movement, with two sets of counting registers, which are alternately thrown into action. The principal mechanism of this counter is shown in Fig. 3. A is the wheel of a clock rotating in two minutes, or other fixed interval of time, and having its motion altogether independent of the other mechanism. On the edge of this wheel are two indentations, *a* and a^2, exactly at opposite sides; the indentations are abrupt on one side, and rise gradually with a curve on the other. Beneath the wheel is a lever B, pivoted at one end, and forced upward in contact with the wheel A, by a spring C at the other end. In the centre of this arm or lever B, is a double knife-edge *e*, projecting above and below the lever, the upper side engaging with the wheel A, the lower side engaging with the vibrating arm D. The arm D is pivoted at its centre on the pin *d'*, its lower end carries a shaft *g*, which receives its motion from the engine. Upon the end of this shaft is placed a ring of india-rubber *m*, to give a yielding pressure upon the registering wheels E H. Two spring bars, N *k*, are riveted to the arm D; they pass upward at the rear of the disc-wheel A. The registering wheel E, having numbers placed around its periphery, turns freely on a centre-pin. A pin h^2, projecting from this wheel at the rear, acts as a stop to keep the figure 0 always at the bottom, when the wheel is liberated to find its own position. H is a similar registering wheel, placed about one-sixteenth of an inch from the indiarubber friction wheel *m*. P is a double-arm lever; its lower arm acts as a pawl, which falls into holes in the wheel E. It is moved at the proper instant of time by a pin projecting from the front of the wheel A. A similar double-arm lever R operates the wheel H. The clock being set in motion, the wheel A rotates once in two minutes. When it has arrived at the position shown, the lower knife-edge *e* is depressed so as to hold the friction wheel *m* against the wheel E, in which position it remains until the notch a^2 arrives at the knife-edge *e*. At this instant the pin, which projects at the front and rear of the wheel A, puts a tension upon the spring bar K, so that when the knife-edge falls into the notch a^2, the friction pulley *m* is forced over in contact with the wheel H, and then the knife-edge descends again, on the other side of the arm D; thus the arm vibrates suddenly from one side to the other at fixed intervals of time. Now, supposing a rotating motion to be given to the wheel *m* by the engine, whilst this wheel is in contact with the register E, this register will continue to count until the wheel *m* is released from contact. When this takes place, the pawl P holds the register in position, and the pointer *p'* shows the number of revolutions made during the last minute H is counting, while E is stationary. The instant before the minute is up, the pin projecting at the front of the wheel A, operates the pawl P, and liberates the register E, which is returned by a hair-spring S to its first position, with 0 at the bottom opposite the point P'.

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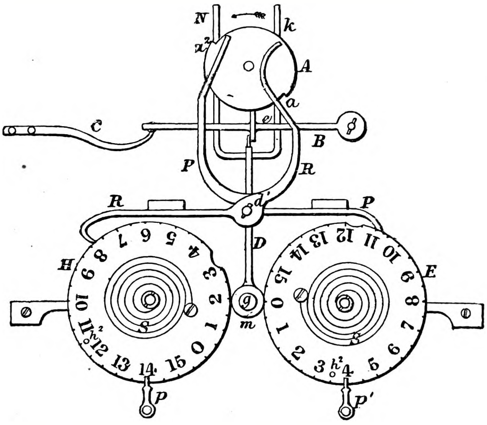

Indicators have also been constructed upon the hydro-governor principle, in which a fluid is injected into a tube by means of piston or rotary pump, and ejected through suitable outlets, the speed being measured by the height of the water. Reynolds suggested in 1874 that a wire heated by electricity, the heat varying with the square of the amount of current, and this with the number of electrical contacts established, should cause the expansion of a metallic bar with which the wire connects, and so indicate the speed by the amount of expansion.

Westinghouse Train Speed-Recorder.—For indicating the speed of locomotive engines the Westinghouse Train speed-Indicator has been very successfully used. It will not only show the speed of a train at any given instant, but will also allow of diagrams being taken, recording the fluctuations or diminutions of that speed caused by the application of the brake. It is shown in two forms, Figs. 4 and 5 being intended for fixing in a carriage or van, and Fig. 6 being adapted for use on an engine, the pumps for supplying water under pressure being in this latter case omitted, and water for actuating the apparatus being drawn from the boiler. In other respects, with the exception of some minor details, the two forms are identical.

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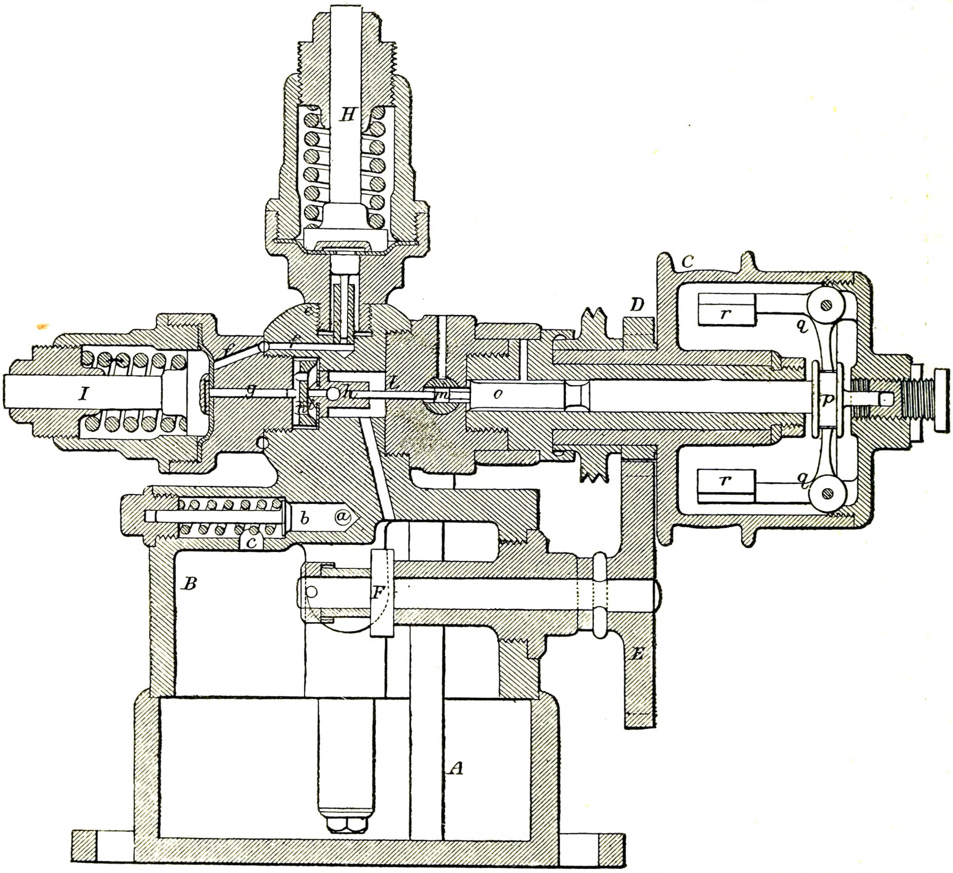

The principle upon which the apparatus acts, consists in controlling the escape of water under pressure, by means of a small valve loaded by the action of centrifugal force, the arrangement being such that the higher the speed at which the apparatus is driven, the greater will be the pressure exerted by certain revolving weights upon the escape-valve, and the higher therefore the pressure maintained within the chamber with which this valve communicates, this chamber constantly receiving a supply of water, either from pumps or from the engine boiler. A pressure gauge affixed to the chamber containing the water under pressure, thus affords, by its indications, information as to the speed at which the apparatus is being driven.

Referring to Figs. 4 and 5, it will be seen that the apparatus consists of a base A, forming a water-tank, there being bolted down to this base a casting B carrying all the rest of the parts. To one side of the casting B is fixed a tubular axis, on which is mounted the pulley or casing C, driven by a belt from another pulley on any convenient axle, care being taken, however, that the wheels on the axle are not fitted with brake-blocks. Fixed to the pulley C is a pinion D, which gears into a small spur-wheel E, mounted on a spindle provided at its other end with a disc-crank F. From this crank are led off two connecting rods G G, which work small plunger pumps drawing water from the water-chamber A. The arrangement is clearly shown in Fig. 5, from which it will be seen that the pistons or short plungers of the pumps are forced outwards by springs, so that the connecting rods work constantly in compression, and the pumps can thus be driven at a high speed.

The two pumps deliver water through channels *a a* into the channel *b*, which is fitted with a small spring loaded relief valve, Fig. 4, this valve when open allowing any excess of water to escape through the hole *c* back into the water-chamber A. Communicating with the passages *a a* there is also another channel *d*, Fig. 5. This passage is fitted with small check valve, and through it the water delivered from the pumps can flow up to the socket *e*, into which the spring accumulator H, Fig. 4, is screwed. This accumulator consists of an indiarubber diaphragm, having on its under side a small piston against which the water acts, while on its upper side is another piston, forced downwards by a spiral spring. The lower piston has a small rod projecting from it, this rod being very slightly tapered, and the water on leaving the accumulator passing down around it to a channel *f f*, leading to a second accumulator I. This I accumulator is similar, with the exception that it is disposed horizontally, instead of vertically, and by the time the water reaches it, the pulsations caused by the action of the pumps are entirely destroyed. In I the water may thus be considered to be contained at a steady pressure.

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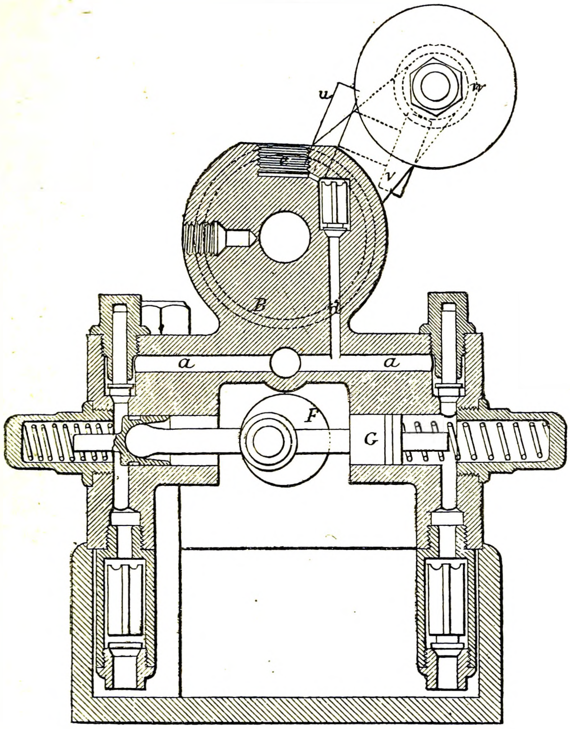

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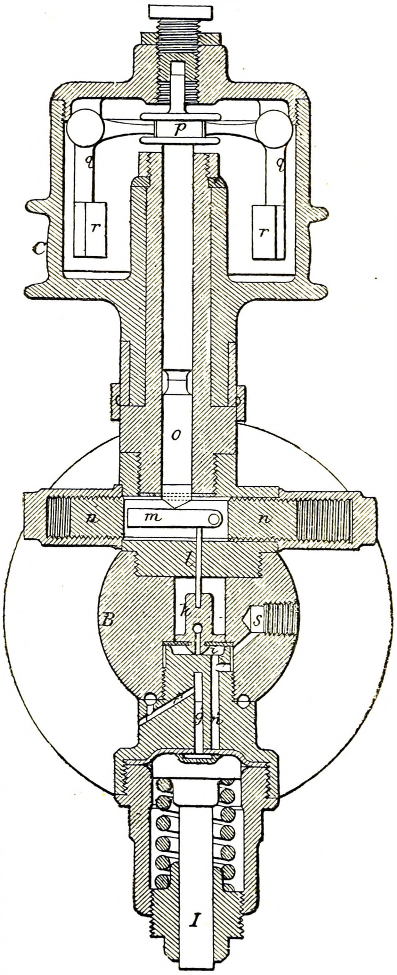

When the instrument is fixed on an engine, and the supply of water required is drawn from the boiler instead of being supplied by pumps, the first accumulator is dispensed with, as shown in Fig. 6. In this case, the water instead of entering the accumulator near the periphery, and escaping at the centre around a needle attached to the ram, follows the opposite course, entering through the passage *f*, Fig. 6, passing into the accumulator around the needle *g'*, and escaping through the passage *n'* to the regulating escape valve.

Returning to Fig. 4, it will be seen that the water can escape from the second accumulator past the needle *g* into the passage *h*, which is connected by small holes with a recess *i*, covered by a thin indiarubber diaphragm attached to the relief valve *k*. The form of this valve is such that when raised from its seat, the water flows out through a central opening in the valve into a small chamber, from which it can return through a passage, shown in Fig. 4, into the water-reservoir A.

It will be seen from Figs. 4 and 6, that the relief valve *k* has attached to it a rod *l*, which takes a bearing against a small horizontal lever *m*. This lever is also pressed against at another point by the rod or spindle *o*; the lever, Fig. 6, is contained in a recess or mortice cut in a bar *n*, so that by turning the screwed caps with which the ends of this bar are fitted, the lever can be shifted longitudinally, and the ratio which the pressure exerted by the spindle *o*, shall bear to that transmitted to the rod *l*, can thus be adjusted with great delicacy.

The spindle *o* extends through the tubular axis on which the pulley C is mounted, and is provided within that pulley with the grooved collar *p*, which takes hold of the shorter arms of the two bell-crank levers *q q*. The other arms of these levers carry small weights *r r*, and as the pulley C revolves, the centrifugal force developed tends to spread these weights, and thus, through the intervention of the bell-cranks, exerts a pressure longitudinally on the spindle *o*. But this spindle transmits its pressure through the lever *m* and rod *l* to the escape valve *k*, and thus the pressure with which this valve is loaded depends upon the centrifugal action of the weights *r*.

The centrifugal force exerted by the weights *r*, will vary as the square of the velocity at which the pulley C is driven, and hence the pressure on the escape valve *k*, will also vary as the square of the velocity of the pulley C, from which may be deduced the square of the velocity at which the train is moving. But a constant supply of water is delivered to the accumulator I from the pumps, or from the engine boiler, as the case may be, and the pressure maintained within this accumulator is controlled by the load on the escape valve *k*, hence a pressure gauge placed in communication with the accumulator I, will indicate pressures which are proportional to the squares of the speeds of the train. To connect it with the accumulator I, the pressure gauge is screwed into the socket *s*, Fig. 6. From the indications of this gauge, the speed of the train at any instant can be at once ascertained.

To be able to take a diagram recording the decrease of speed after the application of a brake, the apparatus is fitted with attachments for connecting to it a suitable indicator. This indicator is connected at *s*, Fig. 6, at the same point as the pressure gauge. Referring to Figs. 4 and 5, it will be seen that the pulley C has fixed to it a short worm, into gear with which the small worm-wheel *u* can be placed. Another worm *v*, on the same axis as the worm-wheel *u*, drives another worm-wheel *w*, and a slow motion is given to the disc from which the cord for moving the paper drum of the indicator is driven. A slow motion is thus obtained for the drum of the indicator. The indicator employed is not shown, but it is similar to the ordinary steam-engine indicator, except that the paper drum is somewhat larger, its circumference being 12 in.

If now the gear for giving motion to the paper drum be thrown into action, when the brake is applied, the pencil of the indicator being at the same time in contact with the paper, it is evident that as the speed of the train becomes reduced, the pencil of the indicator will fall, and this downward movement, combined with the rotary motion of the drum, will cause an inclined line to be traced on the paper, the height of this line above zero, at any given point, being a measure of the speed of the train, at the corresponding point of its forward movement.

To explain this better, we reproduce to a reduced scale in Figs. 7 to 10 some diagrams taken by this apparatus on a train on the Pennsylvania Railroad, Pittsburg division. The train on which these experiments were made weighed about 170 tons, and consisted of an engine and tender and six double bogie-cars, the whole of the wheels on the train, with the exception of those of the engine truck, being fitted with single brake-blocks actuated by the Westinghouse automatic brake. The speed indicator during the trial received its motion from the front axle of the engine, and the case or pulley C, Figs. 4 to 6, containing the bell-cranks with the weighted arms, was driven so that

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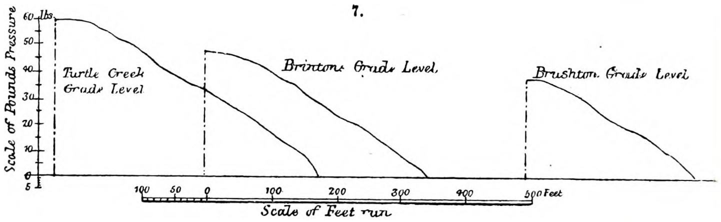

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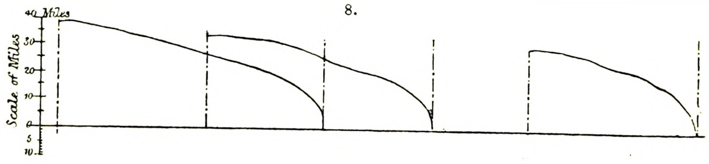

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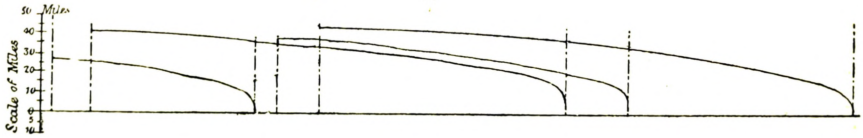

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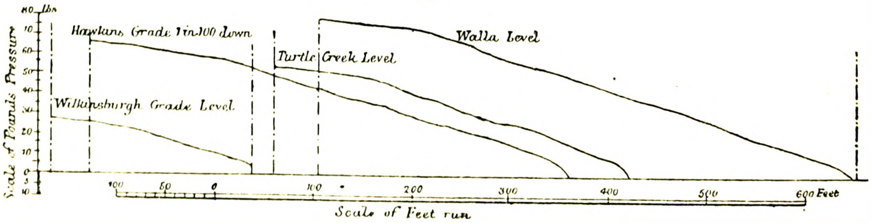


it made one revolution for each 6 ft. of forward movement of the train. The paper drum of the indicator revolved once for every 1200 ft. of forward movement of the train. The instrument is, however, provided with spare gears so that a slower movement of the paper drum can be given if required. Of the diagrams annexed the three in the upper row correspond to stops made under the following conditions.

Place where Stop was made.	Speed in Miles an Hour.	Distance Run after Application of Brake.
	miles	ft.
Turtle Creek, line level	39	412
Brintons "	34¾	352
Brushton "	31	260

The four other diagrams in the third row refer to experiments, of which the particulars are as follows;—

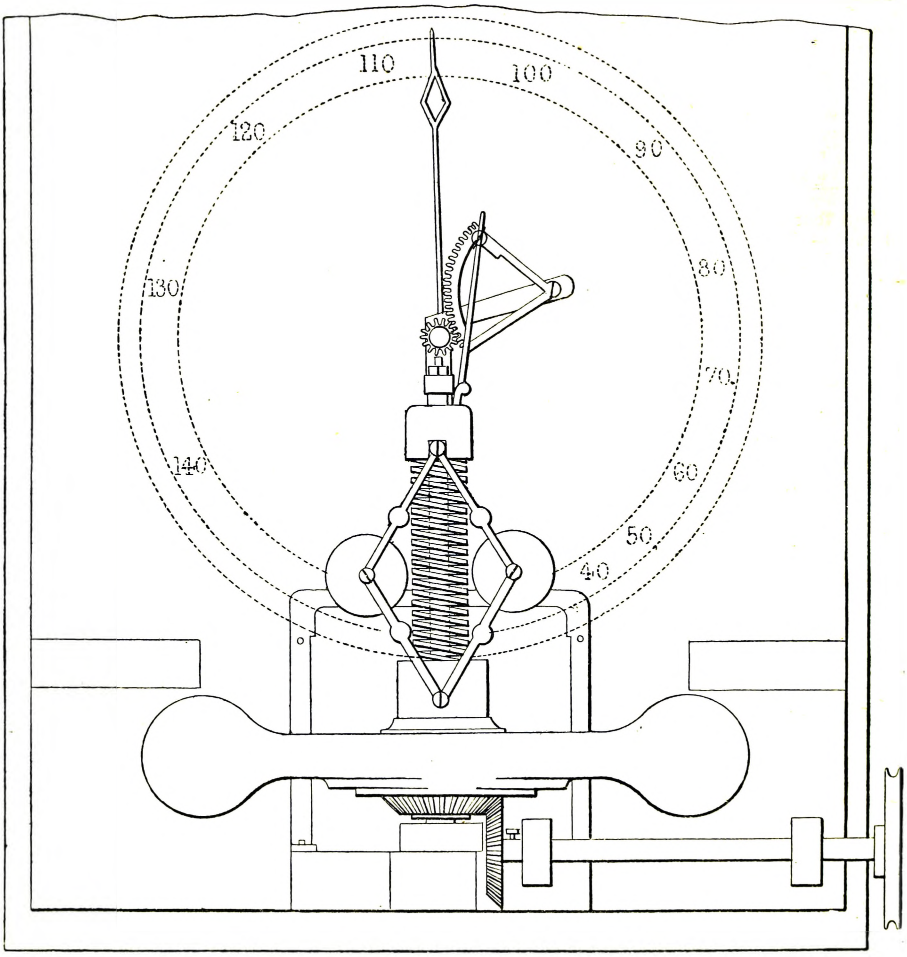
Place where Stop was made.	Air Pressure Pounds per Square Inch.	Speed in Miles an Hour.	Distance Run after Application of Brakes.	Time making Stop.	Speed in Miles an Hour after Running the Subjoined Distances beyond Point of Application of the Brake.				
					100 ft.	200 ft.	300 ft.	400 ft.	500 ft.
	lb.	miles.	ft.	sec.	miles.	miles.	miles.	miles.	miles.
Wilkinsburgh ..	70	26½	205	not taken	22	..	..	..	..
Hawkins	85	40¾	484	14	39	34	29½	22	..
Turtle Creek ..	90	37	364	13	34¼	27¼	19	..	..
Walls	85	43¾	550	15	42½	38	33	26¼	17¾

The performance of the brake during these trials was, as will be seen, admirable; as we have already explained, heights in these diagrams represent pressures in the accumulator of the speed-indicator, and these pressures again are proportioned to the squares of the speeds. In the particular instrument, Figs. 4, 5, and 6, the square of the speed in miles an hour multiplied by 0·04 gives the corresponding pressure in pounds per square inch in the accumulator. It is thus easy to reduce the pressure curves drawn by the indicator to the equivalent speed curves, and this we have had done for the several experiments above referred to, each pressure curve having the corresponding speed curve shown below it.

It is evident that the curves drawn by the instrument, afford the fullest possible information respecting the action of the brake with which the train is fitted. Thus not only do they show the distance run and the mean retarding force, but they also afford data for calculating the retarding force exerted at each part of the stop, and thus show whether the brake power was applied promptly, as it should be to obtain the best results, or whether it only came into action gradually, and thus involved a loss of time at the commencement of the operation, when the train was moving most quickly.

Hearson's Strophometer.—The employment of the governor action, as it is called, for the purpose of obtaining an indication of speed, has been repeatedly attempted, but hitherto without much success, and chiefly for the following reason; almost all steam engines develop their power by a reciprocating motion, which by means of a crank is transformed into a circular one; thus the turning effort not being uniform, produces an irregularity of motion, which is augmented by the inconstancy of the load, and subjects the engine to great and incessant fluctuations of speed, an exact indication of which would naturally result in an excessive oscillation of the pointer, and render the machine almost useless. This, the chief cause of failure of previously invented machines, is in the strophometer overcome by the employment of a flywheel driven by friction in a peculiar way, the action of which is to eliminate the smaller and more frequent variations of speed, which are only momentary, and obtain an almost constant velocity of rotation. The machine as manufactured by Elliott Brothers, of London, is illustrated in Fig. 11, and has a fixed vertical steel spindle. On the lower part of the spindle a pulley revolves freely. By means of the pulley, the motion, or a multiple of the motion to be indicated, is imparted to the instrument by means of a cord. Resting on the pulley, boss on boss, is a flywheel. When the pulley is driven by the engine, the friction between the two bosses helps to send the flywheel round; but in addition to this, friction from another source helps to propel it. The under face of the flywheel is recessed, and into the recess a pair of studs project up from the pulley. Connected to these studs by light chains is a pair of weights which, when the pulley is in motion, press against the inside of the rim of the flywheel and act frictionally thereon, so as to make the flywheel revolve. With these driving arrangements, the inertia of the flywheel will prevent it from being too easily affected by changes of speed which are not persistent, and thus an almost constant velocity of rotation is obtained. The amount of steady motion thus imparted to the flywheel is measured in the following way;—Surrounding the spindle above the flywheel is a helical wire spring, the bottom end fitting into the oil-cup of the flywheel, and the upper end being secured to a collar, which can slide up and down or revolve freely round the spindle. This collar is connected to the flywheel by four pairs of jointed links, carrying balls on their middle joints. When in motion these balls fly out, and through the connection of the links compress the spring, until it measures the resolved part of the centrifugal force due to the angular velocity. All that is left now is to indicate on an enlarged scale the position of the boss, or compression of the spring. To do this, a light connecting rod from the boss works a toothed sector, which gears into a small pinion on an arbor carrying the pointer, and thus the movement is conveyed to the pointer, which sweeps over the graduated and figured dial.

11.



With respect to the length of the divisions of the dial corresponding to equal increments in velocity, we observe that although the centrifugal force increases or diminishes when the speed increases or diminishes, yet it is not a simple measure of the angular velocity; since it varies, as the product of the radius and the square of the angular velocity. We thus see that the centrifugal force or measure of the velocity increases much faster than the velocity itself, hence, except under peculiar circumstances, the scale of measurements must be a continually increasing one. Accordingly, on the dials of most revolution-indicators we see the graduations for low speeds very close together, and wide apart for high speeds. This, to some extent, impairs the efficiency, and lessens the range of the indication. An interesting feature of the strophometer is that its divisions are nearly all of equal length, produced by this combination of circumstances. As the number of revolutions increases, the centrifugal force increases from two causes, first, because the radius or distance of the balls from the axis increases, and secondly, because the square of the number of revolutions increases. Opposing this there are two influences tending to lessen the effect of the centrifugal force. First, the more the spring is compressed, the greater the force resisting further compression, and, secondly, the more the boss or collar is depressed, the more obliquely the tension of the links acts in pulling it further down. These opposing actions so balance one another, that except at very low speeds, almost exactly equal changes in the position of the pointer correspond to equal changes in the number of revolutions.

The instrument is attached to the machinery, the speed of which it is intended to indicate, by means of a fine piece of gut or cord, which passes round a pulley on the revolving shaft, and round the pulley at the bottom of the strophometer. The dial is graduated, and a convenient multiple of the motion employed to suit the maximum speed, and the range of speed, which the machinery to which it is attached experiences, the strophometer not being allowed to revolve at a greater velocity than 500 revolutions a minute. Thus, if connected to an engine the maximum speed of which is 100 revolutions a minute, a multiplying gear of 5 would be used. To facilitate its attachment to marine engines with large shafts, on which it would be inconvenient to place a pulley, a simple apparatus has been designed. It consists of a wooden roller, which is kept pressed against a flanged coupling of the shaft by means of a spring, and the cord is let round a pulley, on the same spindle as the roller. It is so designed that it may be quickly withdrawn from the coupling and put out of gear, and any slackness of the cord can be easily taken up. When fitted to stationary and other engines, of which the range of speed is small, say from 30 to 50 revolutions a minute, the whole of the circumference of the dial is divided into 20 spaces, which may be subdivided, and a very great delicacy of indication obtained.

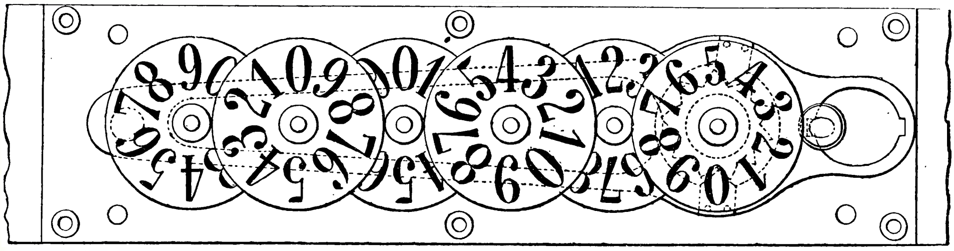
When used on locomotives, the cord should be let round a small pulley on the axle of the following wheels. The dial would, in this case, be graduated to express miles an hour, and the size of the pulley employed would depend on the diameter of the wheels. For fast trains, which run great distances, this instrument would be invaluable as a means of obtaining punctuality.

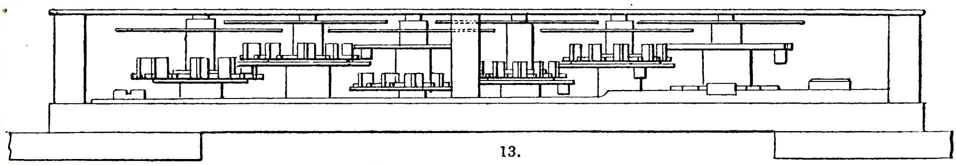
The employment of a toothed sector, with a radial slot to actuate the pinion, allows of a ready method of adjusting the pointer to correctness. The dials are graduated during manufacture, the machine is then fitted with the appropriate multiplying gear, ascertained by moderately careful measurement, and exactness of indication obtained by observation and adjustment when the engines are working.

The instrument is very durable, all the working parts being provided with steel bushes. The lubricating arrangements are well considered; the bottom bearing, where only the friction is important, runs in a cup filled with oil.

Elliott Brothers, of London, construct an indicator, illustrated in Figs. 12 and 13, for recording the number of reciprocal motions, which is based upon the following principles. The reciprocating motion of any convenient part of an engine or machine, is conveyed to a circular disc carrying a pin eccentrically. This pin actuates a rocking arm, which lies along the base-plate, carrying the centres for the arbors of a train of wheels, the arm being slotted and of sufficient width to allow of the arbors passing through it without interfering with its motion; at the opposite extremity to that actuated by the eccentric pin the rocking arm is pivoted. Close to the eccentric pin the rocking arm is drilled out to receive a star wheel, and this star wheel is actuated by two teeth set upon the rocking arm. The star wheel carries on the same arbor a numbered disc, the figures on which appear before an orifice in the face-plate, as the star wheel is rotated by the action of the two teeth on the rocking arm shown in dotted lines Fig. 12. On the same arbor as the star wheel and numbered disc, is a disc carrying a single tooth, which at every tenth complete reciprocating motion, engages with the teeth of a second wheel and records tens, a similar wheel connecting at the proper revolutions with the disc recording hundreds, and so on; the counter recording from units to hundreds of thousands.

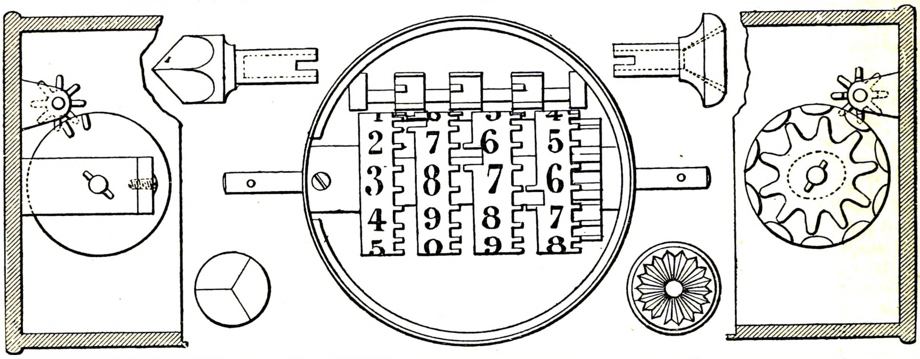
12.





13.

Pocket Revolution-Indicators.—Engineers frequently require to measure the number of revolutions of an engine or machine at times and in positions where an ordinary revolution-indicator is not available. To meet this want there have been constructed small apparatus suitable to be carried in the pocket and easily applied to the extremity of a shaft or axle. One of the most commodious forms is that introduced by T. R. Harding & Son of Leeds, through Elliott Brothers, and illustrated by Figs. 14 to 19. The mechanism, which is extremely simple, is enclosed in a cylindrical case of 1¾ in. diameter by 1 in. depth. Across this cylinder or drum and bearing in its sides, runs an axle which projects through the sides of the case; upon these projecting ends either a punch-head, Fig. 15, or a recessed bitt, Figs. 17 and 18, can be fitted, as it may be required to measure the velocity of an axle or shaft that has a flush end or a pointed end. Hard pressure is sufficient to cause the spindle of the counter, in either case, to revolve with the shaft. Upon the spindle of the counter is fitted eccentrically a star wheel. The spindle also carries four disc wheels loosely fitted, the peripheries of these wheels bear numbers, and are rimmed. The rims are toothed or notched, and upon one side of the rim of the first wheel are notches cut so that at each revolution the star wheel engages into them, and causes the first wheel to be carried forward one unit. Parallel to the main spindle is a second spindle carrying three wheels of eight teeth each, every alternate tooth being of only half the width of the other four. These three wheels serve to connect, at the proper number of revolutions, the disc wheels on the main spindle so as to



14. 16. 17. 19. 15. 18.

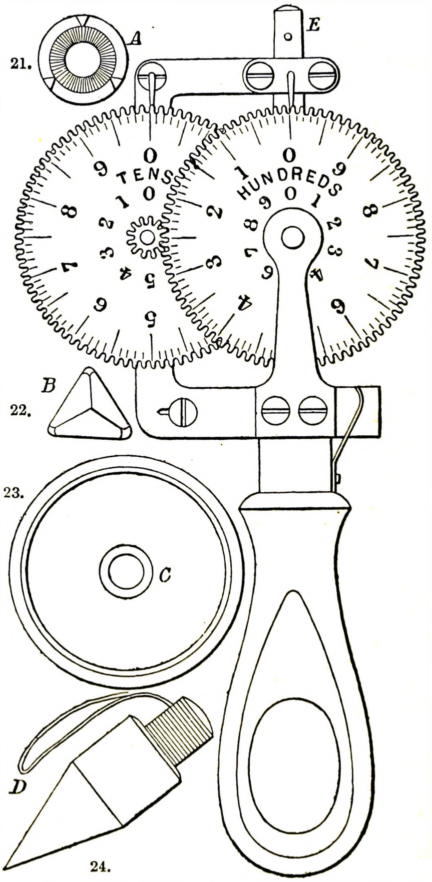
record tens, hundreds, and thousands, and this they effect by locking the two disc wheels together, by one of the four teeth of full width. For this purpose, a single notch is provided on the other side of each disc wheel, with two pin-teeth, raised sufficiently to come into contact with and move the half-width tooth of the locking wheel. The numbers on the rim are presented opposite to a face-plate, which forms with a glass cover one end of the cylindrical case. The instrument records to within a unit of ten thousand.

Another form of pocket counter has been introduced from France by John Browning, of London, and is shown in Figs. 20 to 24. It has the exceptional advantage that it can be instantly set back to zero. On this account, and because the instrument has a separate set of figures for forward and backward motions, the number of revolutions made by a piece of machinery can be read off without making a subtraction sum. In addition to the steel bitts A and B, Figs. 21 and 22, usually employed to communicate the motion of an axle to the counter, a little boxwood wheel C, Fig. 23, accompanies the counter. This wheel is one-tenth of a yard in circumference, and can be employed to measure the forward motion of a pulley-band, and for similar purposes. A punch D, Fig. 24, is occasionally required to make a small hole in an axle to receive the steel bitt; and if a silk thread measuring exactly the length of the pendulum be attached to the punch as a bob, each oscillation marks a second, and by this means a minute can be counted with much greater accuracy than by a watch unprovided with a second-hand.

The Slide Rule.—Slide rules are a purely scientific extension of the common abacus; they are constructed for various kinds of calculation occurring in special businesses, as well as to aid in the ordinary labour of multiplication, division, proportion, and the finding of roots and powers of numbers. The timber merchant, the carpenter, and the gauger have rules divided to answer their special requirements, but all of these rules are based upon the same principle as the common slide rule. We shall therefore describe only the common slide rule.

Many very comprehensive works have been published on the use of this instrument, which include a number of arbitrary rules, far too numerous to be committed to memory, and entailing more labour to be understood than would be involved in the study of logarithms, so far as to enable the student to become independent of rules, and to work from the main principles. A table

20.



21. 22. 23. 24.

of logarithms enables us to do numerically what the slide rule accomplishes mechanically; for instance, the addition of logarithms is performed on the rule by the addition of two lengths, by the placing of the beginning of the slide at one number, and observing the sum indicated by the position of the other number.

The common slide rule usually consists of an ivory or boxwood base which is grooved down the centre, and in the groove is fitted a slide, the face of which is flush with the face of the body or base. There are thus four lines rendered available, namely, the two edges of the slide and the two edges of the groove. We will designate these lines, as is usual, by the letters $\left\{\begin{matrix}A\\B\\C\\D\end{matrix}\right.$, A and D will then be the upper and lower lines on the body of the rule, and B and C the upper and lower lines on the slide.

The line A.—This line is usually divided into two *radii.*

A *radius* consists of a line, the length of which is determined by the length of the rule, divided into 1000 parts, but on the rule the figures between 1 and 10 appear at those divisions which mark the numbers corresponding to the logarithms of 2, 3, 4, and so on. Thus, 1 commences the scale, 2 appears at 301 divisions, 3 at 477 divisions, 4 at 602 divisions, 5 at 699 divisions, 6 at 778 divisions of the scale, and so on; and the intermediate divisions appear at the places corresponding to the logarithms of the intermediate numbers. These lines are then divided logarithmically, the divisions bearing the natural numbers being at distances from 1 determined by the logarithms of those numbers.

The line B is a duplicate of the line A, and the line C is generally also a duplicate.

The line D in the common rules is generally composed of a single radius continued through the entire length of the rule, that is, the divisions on D are double the length of those on A, B, and C. C is generally termed the line of *squares*, and D the line of *square roots*, because there are twice as many divisions on C as there are on D, or, in other words, the logarithms on C are twice the logarithms on D. Therefore when 1 on D coincides with 1 on C, the numbers on D coincident with those on C are the *square roots* of those on C, and conversely the numbers on C coincident with those on D are the *powers* of those on D.

Addition and *Subtraction* cannot be performed by the slide rule, which is a help to calculation only in so far as logarithms are an aid.

Multiplication is performed on the slide rule by the addition of logarithmic lengths, the logarithmic sum or numerical products being obtained by the 1 on B being set below the $\begin{Bmatrix}\text{multiplier}\\\text{multiplicand}\end{Bmatrix}$ on A, the product appearing on A immediately above the $\begin{Bmatrix}\text{multiplicand}\\\text{multiplier}\end{Bmatrix}$ on B. The setting out of the slide thus is in fact merely adding a given logarithmic length on B to a given logarithmic length on A, whence at the sum of the lengths on A the product appears. To those to whom the elementary principles of logarithmic calculation are known, the explanation will be evident.

Division is merely the operation of multiplication performed backwards; instead of adding logarithmic lengths, the logarithmic length representing the dividend, corresponding to the product in multiplication, has subtracted from it the logarithmic length of the divisor, the remainder being the logarithmic length of the quotient. This is actually performed on the rule by taking the dividend on A, beneath which is set on B the divisor, and the quotient appears on A above 1 on B. That is, the logarithmic length represented on B by the length between 1 and the divisor is reckoned backwards, or subtracted, instead of being reckoned forward, or added, as in multiplication.

Proportion.—A given ratio of logarithmic lengths being set up between the lines A and B, by shifting the slide as required, that ratio obtains for all numbers on the two lines. Thus if 2 on B be set under 1 on A, the four will appear under 2, the 10 under 5, and so on.

Fractions are thus easily reducible to their lowest approximate or actual terms by the slide rule.

The secret of success with the slide rule, as regards quickness and accuracy in manipulation, lies not only in understanding the principles of logarithms which underlie its use, but also in a careful consideration of the value of the numeration, as the figures may appear in the first or the second radius. This is easily explained as follows;—It will be clear that if the 1 at the commencement of the rule and first radius be taken to represent unity, the 1 at the commencement of the second radius will represent 10, and the 1 at the end of the second or commencement of a third radius will represent 100. If the latter be taken to represent 1, the second radius will represent tenths, and the first hundredths; and in like manner the value of the 1 at the commencement of the second radius, will be ten times that at the commencement of the first radius, and the one at the end of the second radius 10 times that at the commencement.

The foregoing description, although short, contains sufficient to enable the student to perform all common calculations. Where constants are employed these will appear either as multipliers or divisors, and should be selected for placing on the slides A or B, so as to require as few as possible movements of the slide.

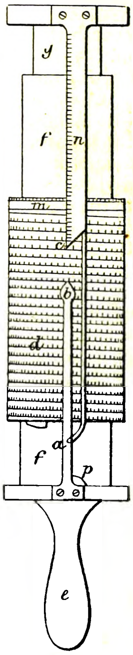
Very many forms of slide rules have been devised. To obtain great length with compactness slide rules have been constructed circular, or the slide has been made a helix working upon a cylinder, or the slide and the body have been replaced by two steel tapes drawn from a case, as in measuring tapes.

The common slide rule constructed as described fails in readily affording means of ascertaining other roots than the square root and its derivatives. To obviate this the writer devised a modification, which is made by Aston and Mander, of London, and in which the line D is transferred to the place of the line C, and has substituted for it a line of equal parts, that is, a line of 1000 equal divisions. The *n*th root of a number being required, the number is found on the line

C, and the number coincident on the line D of equal parts gives the logarithm of this number. The *n*th part of this logarithm having been found by means of the lines A and B, above this *n*th part, taken on the line of equal parts, will be found the root required.

Considering the small amount of labour involved, it is to be regretted that the use of the slide rule is not more generally adopted. The calculations made by its aid are sufficiently accurate for most engineering work of a practical kind. The co-efficient of discharge in hydraulic measurements cannot be approximated within 10 per cent. under ordinary conditions; the specific weight of iron varies 3 to 4 per cent.; the breaking strain of iron admits of errors of at least 5 per cent.; and in electrical calculations the writer has seen twice the amount of work obtained by a testing-room corps employing the slide rule instead of a table of logarithms. For commercial calculations the slide rule is not so well adapted, but it has met with extensive use in many colliery offices, for the purpose of checking calculations for wages.

25.

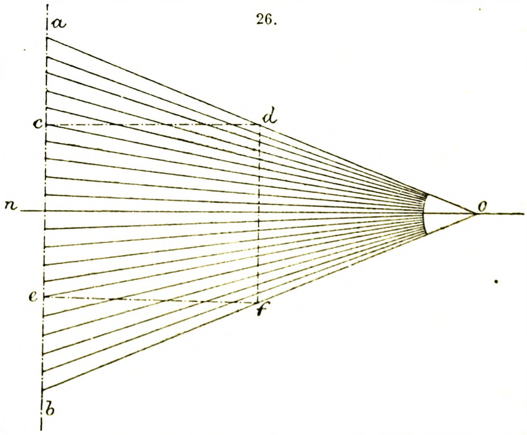


The ordinary slide rule, the scale of which is one foot in length, admits of obtaining correct solutions to within one two-hundredth part of the whole. But Professor George Fuller has designed a spiral slide rule giving solutions within one ten-thousandth part of the whole. A slide rule to be efficient, so that calculations may be made by it with ease and rapidity, and practically correct results obtained, should have the logarithmic scale of such length, that the space between any two consecutive numbers is large enough to be easily distinguished by the unaided eye; the scale should be read by indices, and not as in the present rules; and the number of divisions should be so great and distinctly marked, that the result to be obtained may be easily read and practically correct. This combination, it is believed, is attained in the spiral slide rule. This rule, Fig. 25, consists of a cylinder *d*, that can be moved up and down upon, and turned round, an axis *f*, which is held by a handle *e*. Upon this cylinder is wound in a spiral a single logarithmic scale. Fixed to the handle is an index *b*. Two other indices, *c* and *a*, whose distance apart is the axial length of the complete spiral, are fixed to the cylinder *g*. This cylinder slides in *f* like a telescope tube, and thus enables the operator to place these indices in any required position relative to *d*. Two stops, one not shown in the Fig., and one at *p*, are so fixed that when they are brought in contact, the index *b* points to the commencement of the scale. *n* and *m* are two scales, the one on the piece carrying the movable indices, the other on the cylinder *d*.

It will at once be seen that by this arrangement the logarithmic scale can be made of great length, and the instrument kept of a convenient size for use. It requires only one logarithmic scale, so that every inch of the spiral scale is equivalent to two of the ordinary straight rule. The scale is made 500 in. long, and is therefore equivalent to a straight rule, 83 ft. 4 in. long. This allows of results being obtained to one ten-thousandth part of the whole; and to produce an error of one part in 200 there must be, either in setting or reading, an error of one and one-tenth inch.

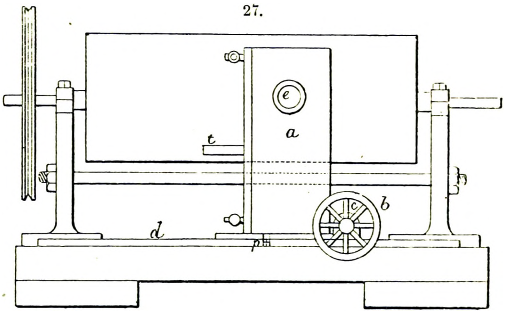
Cycloscope.—If a number of dots at equal intervals are viewed in a mirror, or through a lens attached to a tuning-fork, then, in virtue of the retention of images on the retina, the dots will appear as straight lines when the fork is set in vibration. If motion is given to the dots at right angles to the direction of their images, the two combined rectilinear motions produce the appearance of a sinuous line, or wave form. The height of this wave will depend on the amplitude of vibration of the fork, while the wave length will depend on the relation of the speed of the dots to the period of the fork. If certain ratios obtain between the velocity of the dots and the period of the fork, the waves will be stationary. If the velocity of the dots is slightly greater or less, the wave will be the same in form as that which the exact ratio would give, but it will have a slow progressive motion. This progressive motion will be in the same direction as that in which the dots move if their velocity is too great, and in the reverse direction if it is too small. If the velocity of the dots is such that the time occupied by each dot in passing over the interval between two adjacent dots, is exactly equal to the period of one complete vibration, a single stationary wave is produced. If two intervals are traversed in the same time, a compound double wave will be obtained. More complex forms may be produced. By varying the velocity of the dots, other waves can be obtained of the same form but of different lengths. Thus if two complete vibrations take place in the time of passing of a dot over one interval, a new single wave is produced. It remains to show how the above principles can be utilized. A practical difficulty arises, however, in placing a series of dots round a drum, for instance, with a fork or reed vibrating sixty times a second, the perimeter of the drum would have to be divided into 342·8571 intervals. If, instead of dots, equidistant lines are placed round a drum, parallel to its axis, and are observed through a slit attached to a fork, or reed, similar waves to those described are formed. A piece of

26.



paper is prepared by ruling lines as in Fig. 26, which all converge in a point *o*, and pass through equidistant points on the line *a b*, and a rectangular portion, *c d e f*, is cut out, the size of the latter being just sufficient to wrap round the drum. These lines, when viewed through the slit, act as an infinite series of dots equidistant in each series. Thus, if the convergent lines are so drawn, that their intervals on *c e* are such as to suit the maximum velocity V, and the intervals on *d f*, the minimum velocity *v* to be measured, then between *c e* and *d f* there will be positions which will give stationary waves for every velocity between V and *v*. Moreover, equal distances along the drum correspond to equal differences of velocities; thus, if V is sixty, and *v* twenty rotations a minute, the positions corresponding to velocities of 50, 40, and 30 will be found by simply dividing *c d* into four equal parts, and by further subdivision the positions corresponding to all velocities between V and *v* can be obtained.

In the Cycloscope, as at present constructed, a box *a*, Figs. 27 and 28, showing elevation and plan, containing a reed, to the tongue of which a piece of very thin zinc, with a fine slit, has been soldered, traverses on a slide in front of a drum carrying paper, ruled as described. Motion is given by a hand-wheel *b*, to a pinion *c* on the same axis, the pinion gearing into a rack attached to the slide *d*. A pointer *p*, attached to the reed-box, indicates on a scale *s s* the speed corresponding to any position of the reed-box. A vernier might be employed in place of the pointer *p*, by which the primary divisions could be subdivided into ten or a hundred parts. To make the waves more clearly visible, two small lenses *e e* are employed, fixed in the front and back of the reed-box. The lens on the back of the box throws an image of the lines on the slit; that in front magnifies this image, and thus parallax is avoided. In the early experiments, it was found difficult to keep up a sufficient supply of air to the reed, without a considerable pumping power and large conducting tubes. By the utilization of the principle of the injector, or jet pump, this difficulty has been entirely removed. The air is supplied through a small flexible indiarubber tube from a pair of foot-bellows. This tube terminates in a small glass tube, drawn out to leave a narrow jet $1\frac{1}{2}$ mm. in diameter. This fine jet is passed through a cork, fitted into a wide brass tube *k*, fixed into the lower part of the back of the reed-box. The lower part of the brass tube is cut away to allow free access to the surrounding air. Air, of pressure about equal to a column of water 20 or 25 cm. in height, is forced through the jet, and the reed vibrates perfectly, the mean pressure of air in the reed-box being only about equal to a column of water $1\frac{1}{2}$ mm. in height. The graduation of the scale should be performed after the paper is mounted on the drum. The latter may be conveniently arranged, so that the centre line *n o*, Fig. 26, falls opposite the junction. The lines must now be counted round at any two intersections, and the period of the reed, sixty complete vibrations a second, being known, the velocities which are required to produce stationary waves at these two positions can be readily calculated. Two divisions on the scale being thus obtained, the remaining divisions are found by subdivision.



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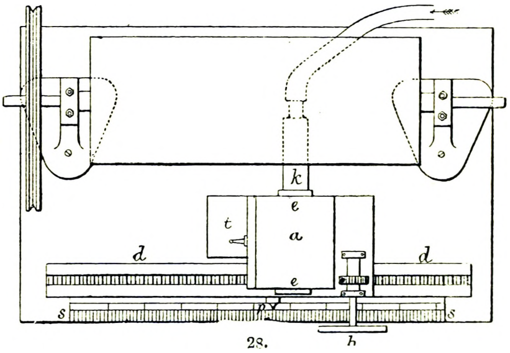


28.

To make a reading it will be necessary to start the reed and to move the hand-wheel *b*, until a stationary double wave is seen through the lenses *e e*; the pointer will then indicate the speed of the drum. It has so far been assumed that the period of a fork or reed is absolutely constant. This is not the case, as the fork varies slightly with temperature, vibrating more slowly as the metal becomes warmer. In some experiments made with tuning-forks a loss ·011 per cent. per 1° C. was observed. This would be too small to affect the value of the instrument for practical purposes, while, if it were employed for delicate investigations, a correction could readily be applied. Some interesting experiments have been made with discs on the principle of the thaumatrope. If a disc provided with radial slits is driven at a constant speed by clockwork, in front of another disc driven from any machine and provided with a ring of dots, and if N and *n* are the number of rotations of the clock disc and the other disc a minute respectively, S, the number of slits, *d*, the number of dots; then when $\frac{N}{S} = \frac{n}{d}$, *d* dots will be visible and stationary. Thus S and N being given or assumed, *d* can be obtained for any assigned value of *n*. If the machine disc is running a little too fast for the above equation, the dots will appear to move slowly in the *same* direction as this disc; if too slow, they will move in the opposite direction. To all cases where it is necessary to study carefully the working of a machine, the method of the Cycloscope can be applied with advantage, while its great elasticity permits it to be adapted to high or low speeds, long or short ranges of velocity, heavy engine machinery, or light clockwork with equal facility.

AGRICULTURAL IMPLEMENTS.

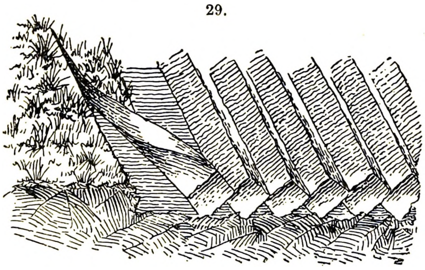
Ploughs.—A plough has to perform three principal functions;—To cut the earth in a vertical plane, forming one of the faces of the band of earth to be raised. To make a horizontal cut so as to isolate this band of earth. To turn over the band thus detached, in order to expose the freshly cut surfaces.

To those three principal functions correspond three especial and essential parts of the plough's mechanism, namely, the coulter, the share, and the mould-board. The mould-board, as the term would indicate, was formerly of wood. It was first made of iron in 1764 by Small, of Berwickshire, Scotland. The other parts of the plough are accessory to these acting parts, and consist of the beam, with or without wheels, by which it is drawn, and the handles by which it is guided. In England ploughs are divided into two classes—*swing* ploughs which are without wheels, and *wheel* ploughs which have wheels before the coulter for the purpose of guiding. The coulter has been constructed as a cutting wheel in advance.

The following are the chief points to be attended to in the construction and management of a plough;—The coulter and share should be sharp, clean, and tapering. The mould-board designed to raise and turn the furrow-slice with as little friction as possible. The beam arranged so that the team may all pull in the line of draught, which should be straight angles to the horses' front. The land side, or part that in some ploughs presses against the unploughed ground and serves to steady the plough, should be parallel to the draught line. The angular presentation of the coulter should be 45°, which is also the angle at which the furrow-slice should be laid over. The depth and width of the furrow-slice should be as 2 : 3.

Figs. 29 to 33 represent different modes of turning furrows adopted in various soils.

29.



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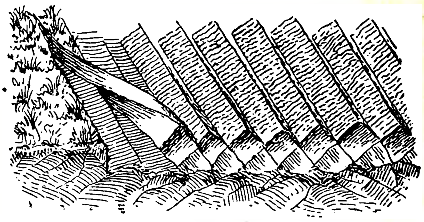

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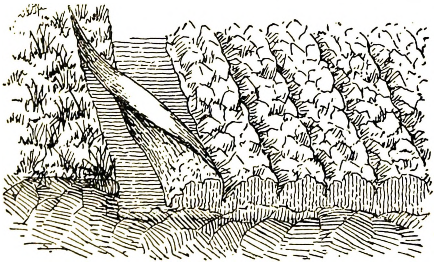

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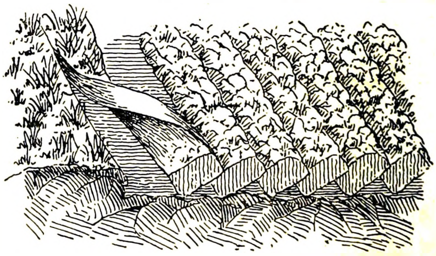

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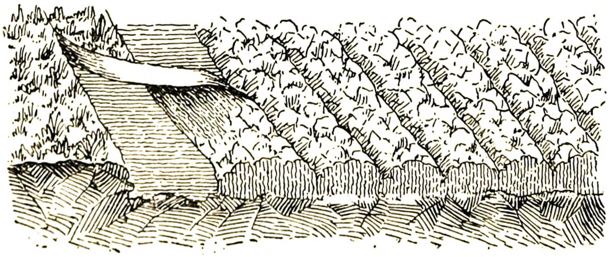
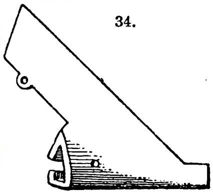


Fig. 29 illustrates the perfectly rectangular furrow with the bed level; Fig. 30 is of a crested furrow; Fig. 31 a completely inverted furrow-slice; Fig. 32 shows the effect of ordinary ploughing, here the furrow-slice is broken; Fig. 33 is of the results of extra wide ploughing, and has a broken furrow.

All good constructors agree in placing the point of the coulter in advance, giving to it an angle of about 30° to 35° with the vertical, so that in encountering an obstacle it may tend to raise the latter from its path with the least possible resistance; the greater the inclination of the coulter the more the plough tends to enter the earth, and this gives to the plough greater stability during its progress. This explains why ploughmen prefer a straight coulter to one that is convex, which tends to throw itself out of the earth; for similar reasons a concave coulter is to be avoided. The section of a coulter through a plane perpendicular to its length presents the form of a triangle, the two longest sides of which include a very acute angle. Well-made coulters for soils of ordinary resistance are about $12\frac{3}{8}$ in. to $12\frac{5}{8}$ in. long, $\frac{3}{8}$ in. to $\frac{3}{4}$ in. deep, and $\frac{3}{16}$ to $\frac{1}{2}$ in. wide at the side opposed to the cut near the point, and $\frac{1}{2}$ in. to $\frac{13}{16}$ in. at the connection with the beam. These dimensions are increased with the length of the coulter and with the resistance of the soil. It is preferable to give the coulter a most simple form, such as that of a rectangle terminated by a curved point, increasing the depth of the plate proportionally to the effort to be supported by the different parts of the piece. If the coulter were independent of other pieces of the plough, and had merely to cut homogeneous earth which closed after its passage, it is clear that the line bisecting the angle of the two forces of the coulter should be that of the direction of movement, but the coulter does not act under these conditions. The band of earth detached is pushed towards the right by the other parts of the plough, and exerts much less pressure on the right face of the coulter than does the firm earth on the left. For this reason the cutting plane of the coulter is parallel to the plane of the body of the plough. In ordinary ploughs the point of the coulter is placed slightly above the point of the share, in order that the share may equally support the weight of the band of earth, and afford equal pressure in the effort to raise the furrow-slice. These details show that the position of the coulter should be accurately regulated, and explain the necessity of fixing it by mechanical means susceptible of somewhat fine adjustment, recognized in ancient ploughs in spite of their otherwise rough appearance. It is not here necessary to refer to the different means adopted to connect the coulter to the beam.

The share is even a more important part of the plough than the coulter. The share acts so as to cut the soil horizontally and continuously, and from this point of view its functions, save in the direction of its work, is the same as that of the coulter. The reasons given to justify the oblique direction of the coulter relatively to the line of movement apply more strongly to the share. Indeed, by the best constructors the straight form of share is adopted. The cutting angle of the share with the draught line varies little in the various ploughs. The ratio of the greatest width of the share to its length is ordinarily comprised between 1 to 3. The width of the share measured perpendicularly to the line of draught, that is to say the length of the sections practically under the soil, should in principle be precisely equal to the width of the band of earth or furrow-slice, and this is very nearly the dimensions adopted on the Continent, whilst English makers give generally less width to their shares. The shares of old ploughs are of chilled iron as to the cutter. Their form approaches that of a right-angled triangle, of which the hypothenuse forms the cutter, and of which the long side of the right triangle forms a kind of plate, by which it is fixed to the mould-board by bolts or rivets. Steel shares are, however, now generally employed, but chilled-iron shares have given excellent results. Shares should be cast with care from bronze models, in order that they may always be interchangeable.

Figs. 34 to 43 are various forms of shares. Figs. 34 and 35 are for wide and deep work respectively. Fig. 36 is adapted for stony land. Fig. 37 is for crested work, Fig. 38 for work cut square.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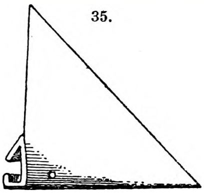
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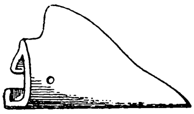
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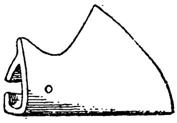
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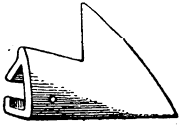
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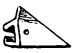
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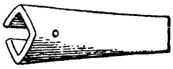
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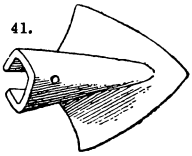
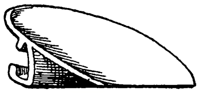

41.

Fig. 39 is a skim-coulter. Fig. 40 is for subsoiling, Fig. 41 for ridging, Fig. 42 for setting out, and Fig. 43 for paring down sidework.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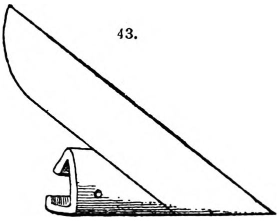

43.

The object of the mould-board is to raise and turn over the furrow-slice detached by the combined action of the coulter and the share. This movement is completed in the length of the mould-board. The geometric form of this essential portion of the plough has received great study at the hands of mathematicians. Jefferson proposed to give the form of the hyperbolic paraboloid; Lambruschini, Ridolfi, and Gasparin prefer the form of the helicoid having for directrix the horizontal line, and for second directrix a quarter turn of a helix, of which this line would be the axis. But it is evident that the best form of mould-board will be determined to a great extent by the nature of the soil, and is not susceptible of purely mathematical calculation. The most practical view to be obtained on this subject will arise from the consideration of the furrow-slice as being under torsion. If this torsion be too great or the curve of torsion too sharp and abrupt, the furrow-slice will be broken; if it be not sharp enough, the plough will experience unnecessary resistance. The mean between these extremes will depend entirely upon the consistency of the soil, because a short torsion that would quickly throw aside a clayey soil of great cohesive power would completely break up a less coherent sandy soil. Thus a fair comparison of two ploughs requires a profound knowledge of practical cultivation.

Regulators.—In order to regulate the depth to which the share shall enter, there is applied to the beam of the plough in several ways, most simply by a mortice and pin, a vertical bar, to which is attached a shoe or a wheel. In swing ploughs a shoe is employed, which, bearing upon the unworked earth, aids the ploughman in maintaining an even depth. In wheel ploughs this shoe is replaced by a wheel or by two wheels, one of which runs on the unworked soil, and the other in the last-made furrow. The means of adjusting these appliances for regulating the depth of the furrow are very numerous, but are easily understood upon inspection.

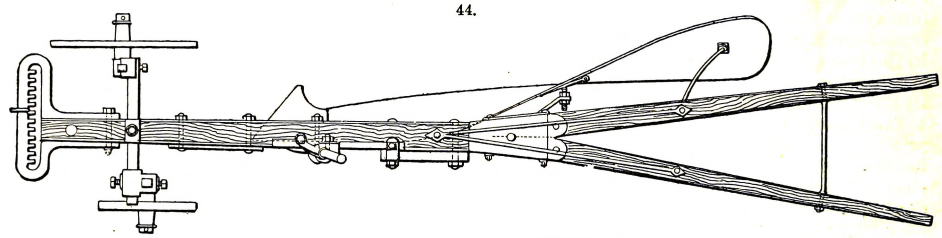
Plough Bridle, Muffle, Cock, or Clevis.—This is the stirrup-shaped piece to which the horses' gear is attached for the draught of the plough, situated at the front extremity of the beam. It is provided with holes or indents for the regulating of the draught line with regard to depth and direction of the furrow.

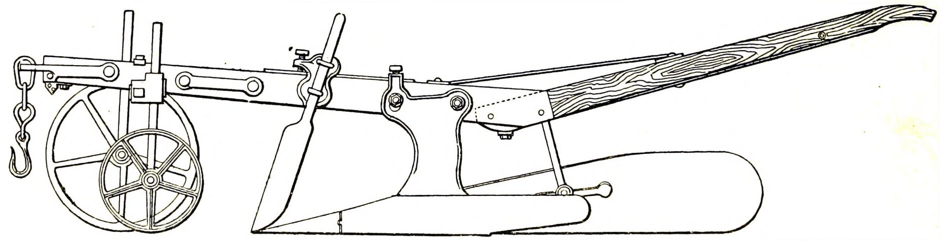
Plough Truck or Carriage.—This is a frame mounted on wheels, sometimes provided for the carriage of the plough over stony roads, or places where the share and coulter are likely to be injured.

Plough Cleaner.—A kind of fork or spud attached to a long handle, with which the ploughman can detach weeds from the share without leaving the handle of the plough.

Hornsby's single and double ploughs consist of a wooden beam with a steel or iron plate on either side, secured to it by through bolts. The slade or slipe and coulter are set towards the central line of the beam, and the upper parts of the stems are curved to allow of their coming to and resting against the outer side of the beam. This arrangement gives great clearance for manure and grass or weeds to get away, and whatever passes back over the rear end of the mould-

44.





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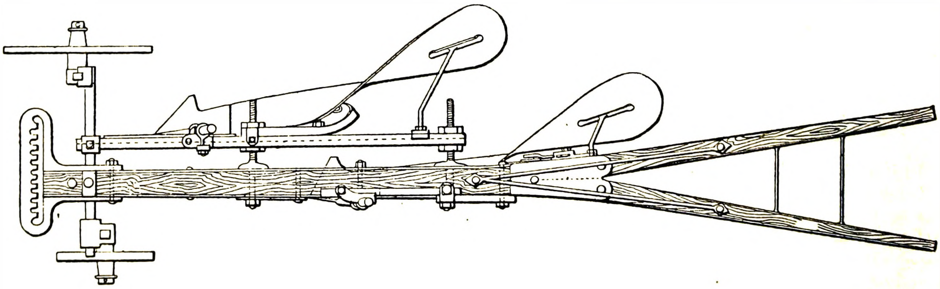
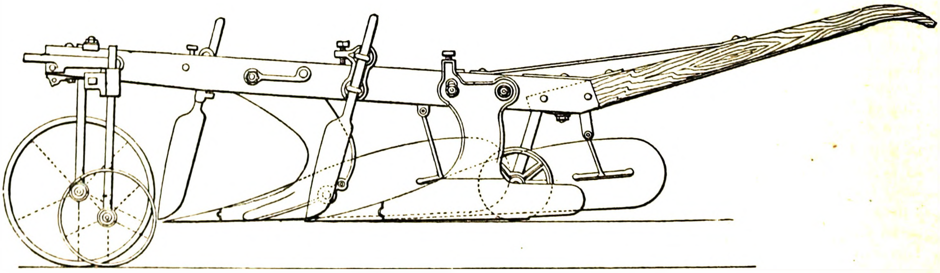


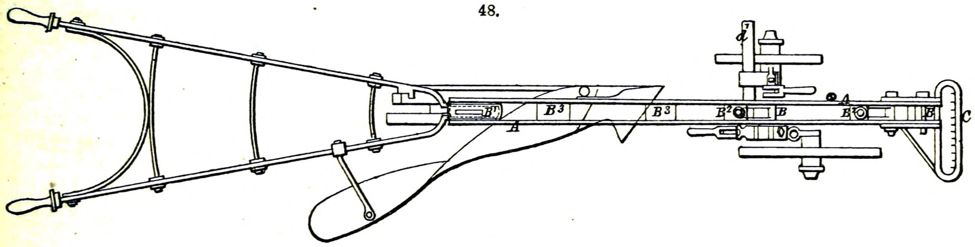


47.

board drops clear away into the bottom of the furrow behind it. The fastenings which attach the plough-body and coulter to the beam can also for this reason be brought closer together, and as the beam is capable of resisting a great strain, the points of the coulter and share always remain approximately opposite one another, whatever strain may be put upon the plough-handles. In double ploughs the additional beam for carrying the second plough is formed of trough iron. This additional beam is carried by two bolts, each having a broad collar to bear against the iron or steel plate of the main beam. The small number of bolts gives great facility for shifting the beam towards or away from the main beam, and again securing it according to the width of the furrow required. Figs. 44 and 45 are elevation and plan of a single-furrow plough; Figs. 46 and 47 of a double-furrow plough.

Howard and Bousfield, of Bedford, have constructed a plough which can be converted into a double plough when desired, and in which every attempt has been made to secure lightness with rigidity. Fig. 48 is a plan of a single plough, Fig. 49 illustrates the conversion into a double plough,

48.



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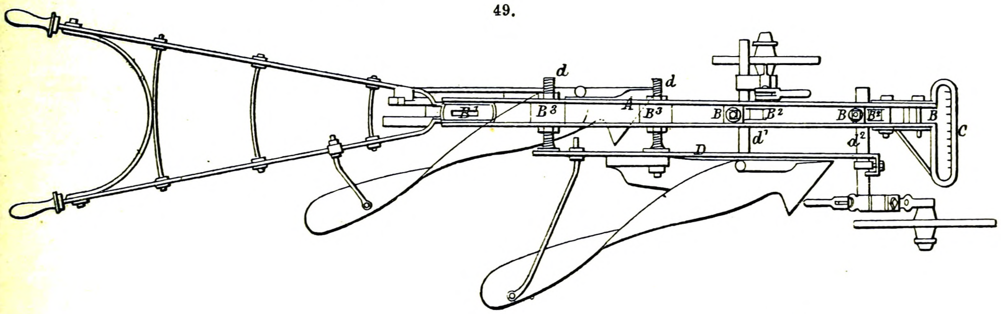
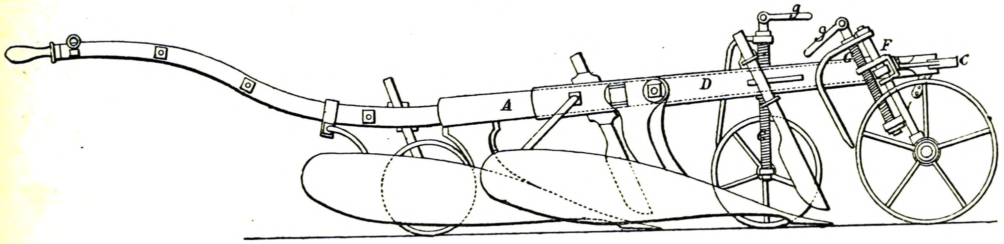


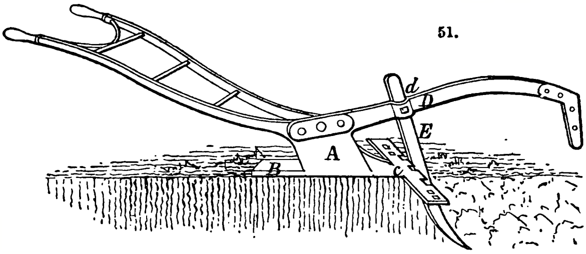


50.

Fig. 50 is a side elevation. A A are taper bars of steel, between which distance-pieces B, B^1, B^2, and B^3 of cast iron are set. The distance-piece B at the head of the beam serves for adjusting the draught hake. In converting the double plough, Fig. 49, into a single plough, Fig. 48, the slide d^2 is removed from its socket in the forward end of the beam, and set back in the position of the slide d^1, of Fig. 49, the slide d^1 being rigidly attached to the beam D, and removable together with that beam. The slide d^2, carrying the furrow wheel when inserted into the backward socket, receives the standard of the land wheel. To facilitate the adjustment of the wheels in respect of depth and ensure rigidity of the wheel fastenings, an arrangement is adopted which gives the ploughman two means for regulating the depth of the ploughing. The wheel standard passes through the wheel slide F, to which it may be secured, if desired, by a loop and binding nut. When, however, this nut is slack, the standard will be free to move up or down in the slide. This is so far the ordinary mode of adjusting the depth of the wheel; and to provide additional means of adjustment, a hole is tapped in the slide to receive a screw G, that is mounted in bearings carried by the wheel standard. The head of this screw is fitted with a handle *g*, by turning which the screw is caused to raise or lower the standard in the slide and adjust the wheel to the required depth. Provision is thus made against failure of the vertical screws, and necessary rigidity given to the wheel standards, independently of the vertical screws during hard work or when the mortices have become worn.

An improved form of drainage plough introduced by Cupaidge is illustrated in Figs. 51 to 53. The ploughshare A has attached to its under side a flat sole-plate B, extending some distance beyond it in the rear, and on the nose of the ploughshare is fitted the socket of the surface sock C, which has three or more notches, *c*, c^1, c^2, in its front edge, the notch *c* being vertically under the draw bar D, while c^1 and c^2 are at any required distance to either side. On the draw bar D is a socket or eye *d*, in which is secured the neck of a coulter-blade E. For making a vertical cut in the soil, a coulter-blade is employed, having a straight neck and fitting with its back edge into the notch *c* of the sock. The blade E is adjustable vertically in the socket *d*, so as to cut the furrow to any required depth in the soil. If it is desired to cut a V-groove or a drain in the soil, this is effected by first fitting to the plough a sock with oblique neck, so as to extend obliquely, say, to the right, fitting into notch c^2 of the sock, and after forming a corresponding oblique cut therewith, a coulter is introduced extending obliquely to the left and fitting into the notch c^1 of the sock. In the holes c^3 of the sock are fitted scribe pins. When it is desired to undercut or make lateral incisions in the cutting, a coulter-blade is employed, Fig. 53, having two lateral blades *f f* at its lowest extremity. By removing the surface sock, putting on the ordinary ploughing sock, and raising the coulter-blade, as in the ordinary plough, the implement may be used as a subsoiling plough.

51.



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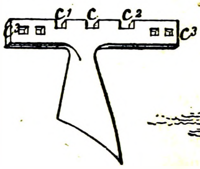

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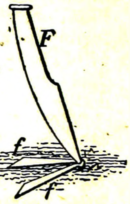

The Mechanical Work expended in the Use of the Plough.—The following condensed table gives the results of a series of trials made with different kinds of ploughs under the auspices of the Royal Agricultural Society of England at Hull in 1873:—

WORK EXPENDED IN THE USE OF PLOUGHS.

Class and Description.	Weight of Plough.			No. of Horses.	Dimensions of Furrow in Inches.		Foot-lbs. of Work done per lb. of Earth raised.	Weight of Earth disturbed per Yard run, in lbs.	Draught in lbs.
	cwt.	qrs.	lbs.		Width.	Depth.			
Wheel ploughs not exceeding 2 cwt.	1	3	26	2	8·96	4·82	12·93	96·	414
	1	3	21	2	9·38	4·85	16·18	101·	545
	2	0	0	2	9·17	4·67	13·41	95·01	424·7
Wheel ploughs not exceeding 2½ cwt. ..		..		3	11·36	6·97	13·05	175·5	764
	2	1	13	3	11·64	6·76	13·77	174·7	802
Swing ploughs not exceeding 2½ cwt. ..		..		2	10·23	5·01	12·71	113·8	482
		..		2	9·37	5·22	15·69	108·5	567
	1	2	3	2	8·9	5·4	15·88	106·7	565
		..		2	9·03	5·64	16·7	113·0	629
	1	3	6	2	9·37	5·22	16·18	103·2	556
		..		2	9·8	5·45	13·17	118·6	520
	1	3	22	2	9·1	5·74	14·62	115·9	565
Double-furrow ploughs not exceeding 3½ cwt.	3	1	8	oxen 2	17·54	5·09	11·31	186·6	704
	3	2	0	horses 3	19·25	5·25	12·43	205·9	853
	2	3	0	3	16·4	5·3	12·69	181·6	768
	3	1	0	3	18·67	5·01	10·57	201·0	708
	3	1	26	3	17·8	4·91	13·39	182·9	816
Double-furrow ploughs not exceeding 5 cwt.	4	1	0	oxen 2	17·3	5·98	14·62	216·1	1053
	4	0	0	horses 4	20·08	5·7	12·57	239·1	1001
	3	0	0	4	19·01	5·64	13·34	224·0	996
Single-furrow plough tested under conditions of double-furrow plough to determine comparative advantages of single and double ploughs ..		..		2	9·37	5·92	17·3	116·0	669

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All these ploughs were tried on a field of second year's seeds, the soil being very dry and hard. Of the work expended by the several parts of the plough, the following deduced from M. Gasparin's calculation, will afford an idea:—

Resistance of the coulter	48·8
Resistance of the share	85·4
Friction of the mould-board	10·5
Raising of the earth by the mould-board	14·7
Friction due to plough	37·0
Total traction	196·4

Steam Cultivation.—Having given some account of the work expended in the cultivation of land by the ordinary horse plough, it may be interesting to record some of the data obtained at the elaborate series of trials of systems of steam cultivation, undertaken by the Royal Agricultural Society of England, at Wolverhampton, in 1871. We shall limit the observations to the systems introduced respectively by the Ravensthorpe Company, the Fisken high-speed system, Messrs. Fowler's and Messrs. Howard's systems. With the Fisken high-speed system the indicated work of engine in foot-lbs. per lb. of earth removed, the mean was 22·9 foot-lbs.; the average foot-lbs. of work per lb. of earth moved by Howard's system was 21·8, which closely agreed with the number for Messrs. Fowler's system. These three systems are all "round-about" systems. The work expended per acre stands in the following order:—

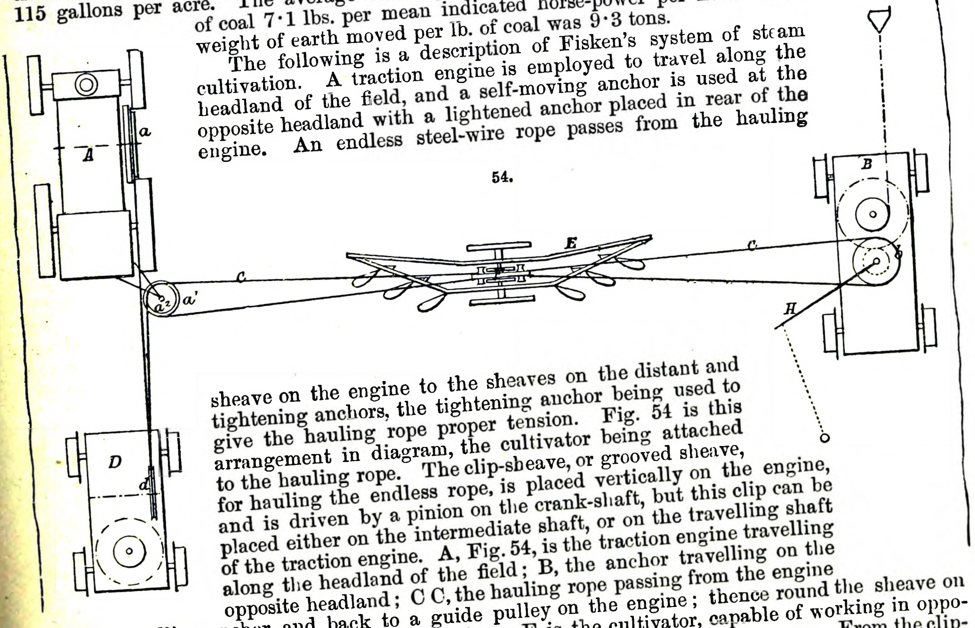
The Fisken high-speed system	22·1 foot-lbs.
J. Fowler & Co.'s system	20·4 "
Howard's system	16·7 "

From these trials a singular and unexpected fact appears deducible, namely, that the absolute work in foot-lbs., necessary to cultivate the land, does not depend materially upon the speed at which it is worked; that is, that the coal and water consumed per acre will be the same if the implement travels fast or slowly. Comparing the resistance of ploughs, diggers, and cultivators respectively on light and heavy land, it is found, on taking averages from all the trials, that the

	At Barnhurst.	At Stafford.
Average foot-lbs. of work indicated per lb. of earth dug or ploughed	17·7	21·7
Average foot-lbs. of work indicated per lb. of earth cultivated	15·2	20·3

thus showing that the change from light to heavy land increased the resistance 28 per cent., and that the diggers and ploughs consumed about 10 per cent. more power than the average of cultivators exhibited. It further appears that ploughing requires rather less power than digging. In these trials it may be taken that the average consumption of coal was 161 lbs. per acre, and that of water 115 gallons per acre. The average consumption of water per lb. of coal was 7·2 lbs., and that of coal 7·1 lbs. per mean indicated horse-power per hour. The weight of earth moved per lb. of coal was 9·3 tons.

The following is a description of Fisken's system of steam cultivation. A traction engine is employed to travel along the headland of the field, and a self-moving anchor is used at the opposite headland with a lightened anchor placed in rear of the engine. An endless steel-wire rope passes from the hauling sheave on the engine to the sheaves on the distant and tightening anchors, the tightening anchor being used to give the hauling rope proper tension. Fig. 54 is this arrangement in diagram, the cultivator being attached to the hauling rope. The clip-sheave, or grooved sheave, for hauling the endless rope, is placed vertically on the engine, and is driven by a pinion on the crank-shaft, but this clip can be placed either on the intermediate shaft, or on the travelling shaft of the traction engine. A, Fig. 54, is the traction engine travelling along the headland of the field; B, the anchor travelling on the opposite headland; C C, the hauling rope passing from the engine to the travelling anchor, and back to a guide pulley on the engine; thence round the sheave on the tightening anchor D, and back to the engine. E is the cultivator, capable of working in opposite directions without reversal of the direction of the traverse of the hauling rope. From the clip-sheave *a*, on the engine, the rope passes round a guide pulley, a^1, hung on the engine, thence along the line of furrows to the sheave *b*, on the anchor B on the opposite headland, returning along the


54.

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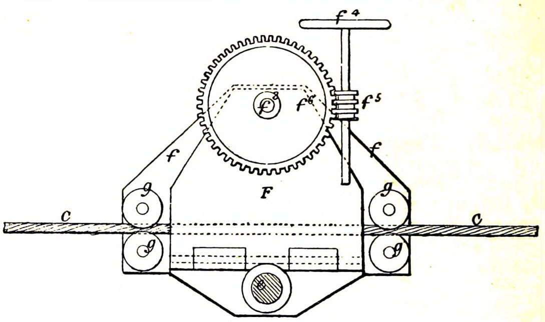
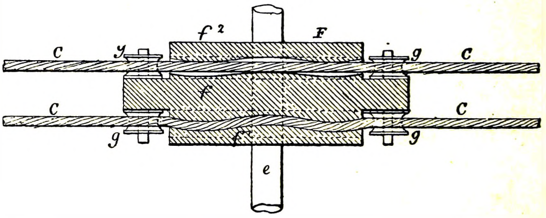
line of furrows to a loose pulley, a^2, on the axle of the pulley a^1, round the sheave d of the tightening anchor D to the main clip-sheave a on the engine. For attaching the hauling rope to the cultivator, there is fixed to the main hauling rod or pin e of the tilling implement a double-jawed longitudinal clip F, Figs. 55 and 56, for receiving and gripping the endless rope. This clip is formed of a fixed plate f, and two movable plates, f^1, f^2, which constitute the gripping jaws. The movable plates are hinged to the fixed plate and are acted on by the tightening screw f^3, which is worked by the ploughman by means of a hand-wheel f^4, the axle of which is fitted with a worm and wheel, f^5, f^6. That part of the hauling rope C, which passes to and from the anchor B, is gripped by the clip F, longitudinal grooves being made in the gripping surfaces for that purpose. To ensure the gripping of the rope the half-grooves are made with undulations. When the ploughman turns the tightening screw in one direction, the leading rope will be gripped and the traverse of the implement will be towards the anchor; when he reverses the direction of the tightening screw, the return rope will be gripped and the implement caused to traverse in the opposite direction. The engine is moved along the headland the required distance by the driver at each bout. The anchor on the opposite headland is also hauled forward at each bout by means of winding gear acting on a rope fixed ahead of the anchor, the winding gear being put in motion by the endless rope sheave on the anchor. For the purpose of regulating the distance which the anchor is to move, the clutch on the travelling anchor B, by which the axle of the sheave b is connected to the winding gear, is acted on by a lever H, Fig. 54, to throw it out of gear and arrest the progress of the anchor. This lever has its full run on the axle of the clutch, and its free end projects landwards and is prolonged so far that the end of the lever will move over a space equal to the distance the anchor has to move at a bout; this requires the lever to move over, say one-third of a circle, more or less. To the outer end of this lever a cord is attached, which is connected with a weight in the rear of the anchor, for the purpose of putting a drag upon the lever as the anchor moves forward. When the implement has completed a bout and it is desired to advance the anchor, the ploughman will move forward the drag weight by means of the lever to the distance required for the next traverse of the anchor. This forward motion of the lever re-engages the clutch, and the anchor then moves forward until the drag of the weight causes the lever to ascend the cam and again lift the clutch out of action. When a portable engine is employed, then a second self-moving anchor is used on the same headland as the portable engine, the two guide pulleys required before on the engine being now mounted on this anchor which is in line with the engine. This latter arrangement requires a greater length of steel rope to stretch double all the length and breadth of the land to be cultivated, and the portable engine must be fitted with a clip-sheave driven by a pinion on the crank-shaft. The second travelling anchor in this arrangement is to be fitted, like that in Fig. 54, with the weighted lever and cam for throwing the clutch out of action.

55.





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Until the year 1876 ordinary steam ploughs were constructed to make furrows of a definite width. The depth to which the land is to be ploughed could be varied within certain limits, but the width of the furrows or their distance from each other could not be varied, because those parts of the implement which cut and turn the furrow, were rigidly secured to the frame of the plough and at the same lateral distance. To make furrows of a different width a separate plough was required. Attempts had certainly been made to render the same plough capable of running furrows of different widths by constructing the plough so that the cutting and turning parts could be shifted to greater or less distance; but these ploughs did not give satisfactory work, except between very small limits. Fisken sought to meet this objection by constructing the frame of the plough, Figs. 57 and 57*, in three parts, bolted together. Figs. 57 and 57* represent a four-furrow frame. The cutting and turning parts of the plough, the coulters, and the skives, which latter carry the shares and the mould-boards are secured to the two outer frames; these frames are similar to each other. The middle part of the frame, which is a very costly portion of a plough, thus serves for all kinds of work, and any kind of agricultural implement used in steam cultivation of land can be attached to this frame.

In 1877 an improved self-moving anchor was introduced by D. Johnson, of Hockley Heath, consisting, Figs. 58 and 59, of a metal frame A mounted on the two rear wheels B and the front wheel C. w is a broad cutting coulter at the rear end of the frame to support the anchor against the side pull of the rope upon it. This coulter D is supported by a vertical shaft d, which carries the pulley E, around which the traction rope i passes. The coulter-shaft d is held firmly by the stay F fixed to the anchor-frame. At the front of the frame A is a second coulter J, for guiding the anchor along the side of the field. The second coulter J is adjusted and fixed on a quadrant *k* by a stop pin. At the rear of the steering or guiding coulter J is a jointed stop and drawing foot G, turning on a joint at *g*, on the frame A. By means of this foot the anchor is fixed in its position during work.

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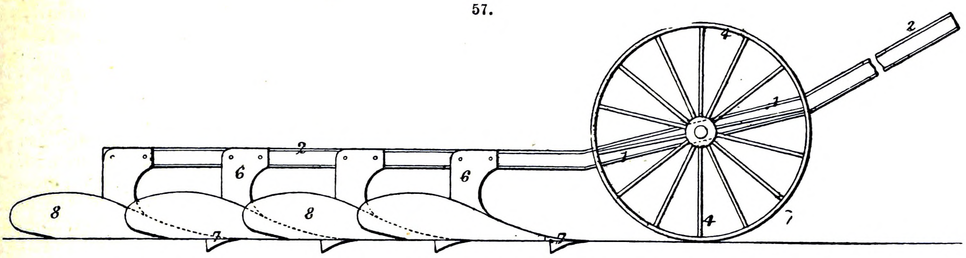
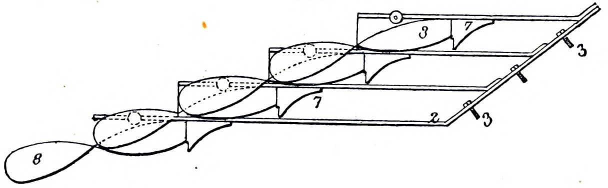


57^{a}.



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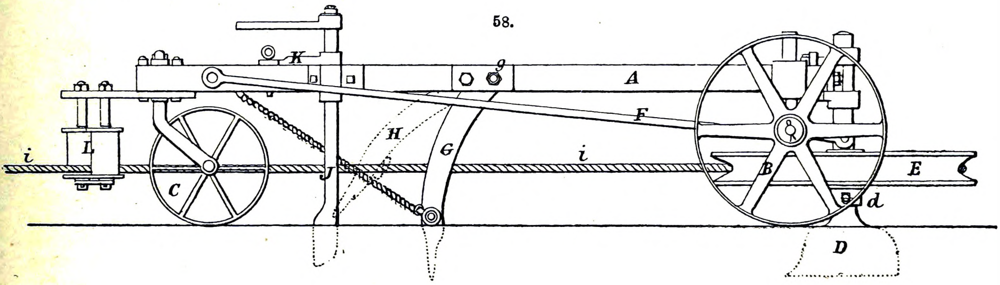

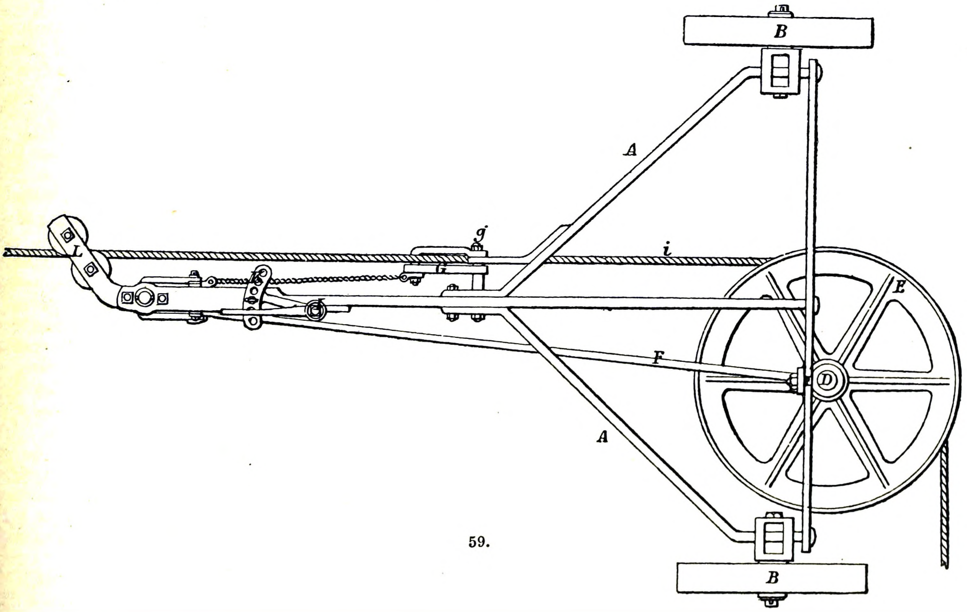

59.

During the normal working of the apparatus, that is, when the anchor is required to be stationary, a knot in the rope *i* does not approach the drawing foot G, but when it is wished to alter the position of the anchor, the reversal of the winding drums or of the windlass at the engine is not effected until the knot bears against and lifts the foot G into the position indicated in dotted lines at H, Fig. 58. The anchor being thus released, the further motion of the traction rope *i*, acting on the foot G, moves the anchor to the required position, the lateral holding coulter D and the guiding coulter J, as the anchor is drawn along by the rope, cutting their way through the land. Thus the motion of the traction rope is made to release the anchor and move it at the proper times, longitudinally down the field towards the traction engine or point of haulage.

A system of steam cultivation by John Fowler and Co., of Leeds, is described in the first volume of this Dictionary; the following is another system adapted to be worked by an ordinary portable or traction engine, and is strong enough to take the power of a 10-horse-power engine. All loose parts in the tackles are dispensed with, and the system can be quickly removed and fixed in position. The plan of working is in one respect different from any proposed. The engine and windlass being placed on one headland, the anchors are let down at the two ends of the same side of the field. The rope being pulled out, the work begins at once along the same headland, the anchors working gradually away from the engine. This method of working gives the advantage of having little rope to pull out in starting, and dispenses with taking anchors and snatchblocks into remote corners of the field; it also secures perfect coiling, as no slackness is occasioned by the movement of the anchors, and every journey of the implement decreases the quantity of rope on the drums.

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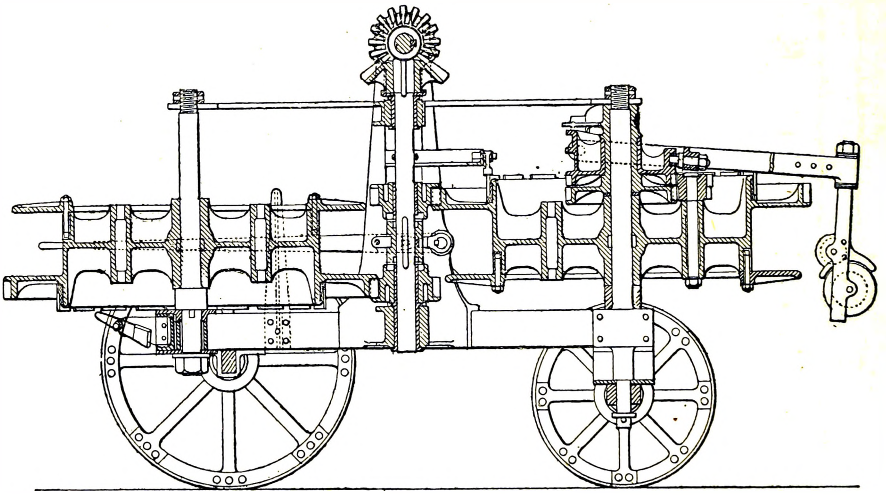

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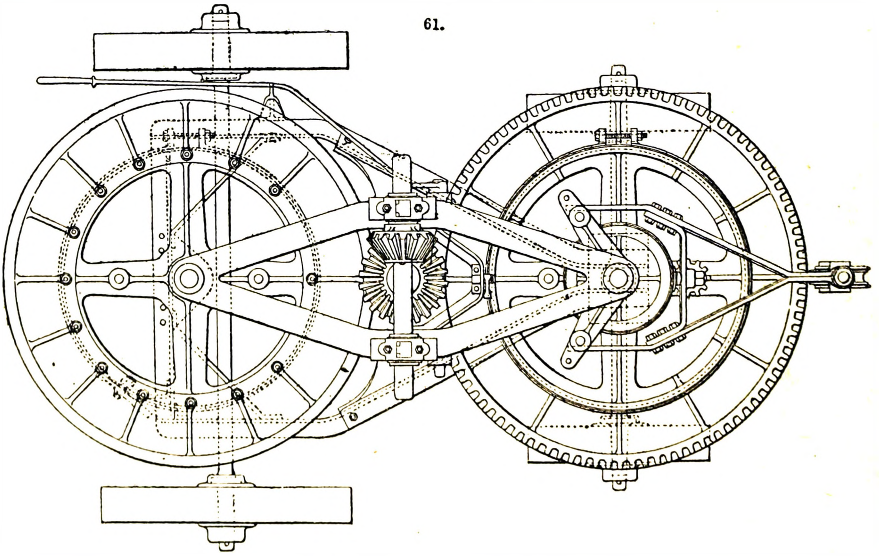

After finishing between the two headlands, the tackle is in a position to plough the headlands without any removal of parts, after which anchors and implement can be hauled back to the windlass by the ploughing rope, and the field cleared of all tackle without the assistance of horses. Two men are required to work this tackle.

The windlass, shown in Figs. 60 to 63 to a very small scale, is constructed on four wrought-iron road wheels. The winding apparatus consists of two horizontal drums, which, by means of coiling gear, wind and unwind the wire rope uniformly without any attention. This is done by a self-acting lever, which carries two vertical guide pulleys, moving slowly up and down, and freely swinging round the drum into any position at which the rope has to work. Thus any undue strain on the rope as well as on the apparatus is completely avoided, and all friction of double snatchblocks, &c., entirely done away with. The rope pays out from the drum at any angle required by the work without

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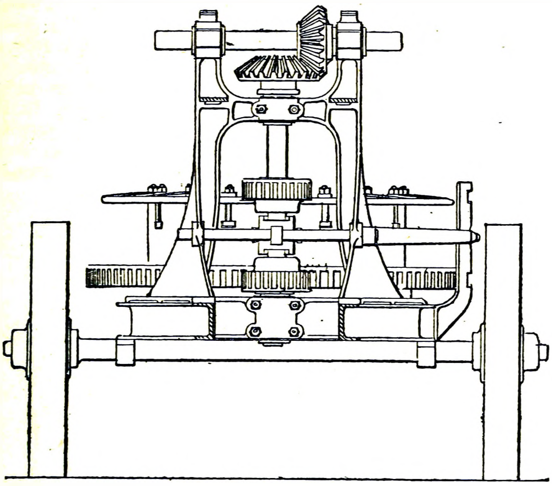

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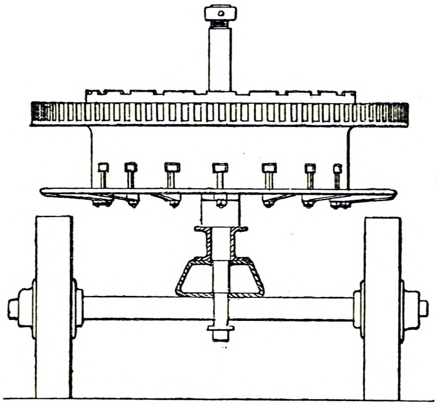
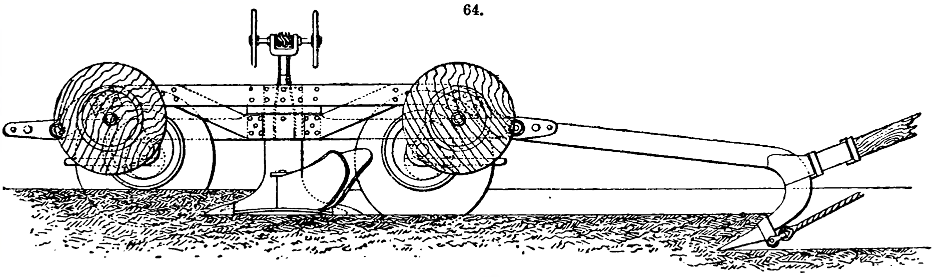


snatchblocks or double snatchblocks being necessary, whilst more perfect coiling is secured by the coiling gear and the peculiar way of working the tackle, previously described, that in any windlass hitherto brought out. In dispensing with the double snatchblock not only wear and tear of the rope is diminished and loss of power avoided, but also a very troublesome item in setting down the tackle in a field is entirely obviated.

For the reclamation of waste land the Sutherland plough has been introduced. This plough, Figs. 64 to 66, constructed by John Fowler and Co., is a framework carried on six wheels or rollers,

64.



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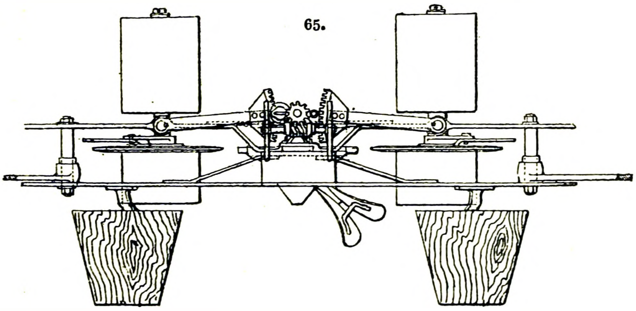

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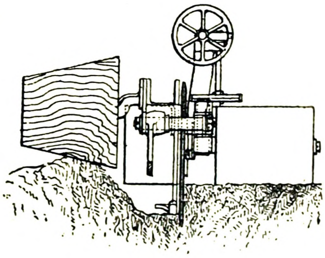
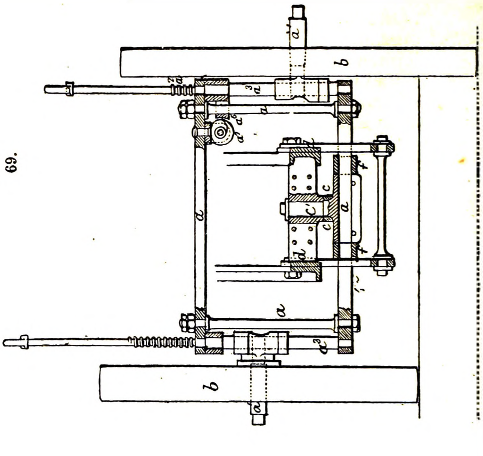


two for the land side, two to press on the top of the furrow, and two in the centre in connection with the coulters which form the steerage. The head of the plough is hung from the centre of the frame, and is double-ended, having a lateral cutting share of a triangular form, so as to cut either way. From the centre of this head there is a double-ended mould-board hung from a centre, which swings



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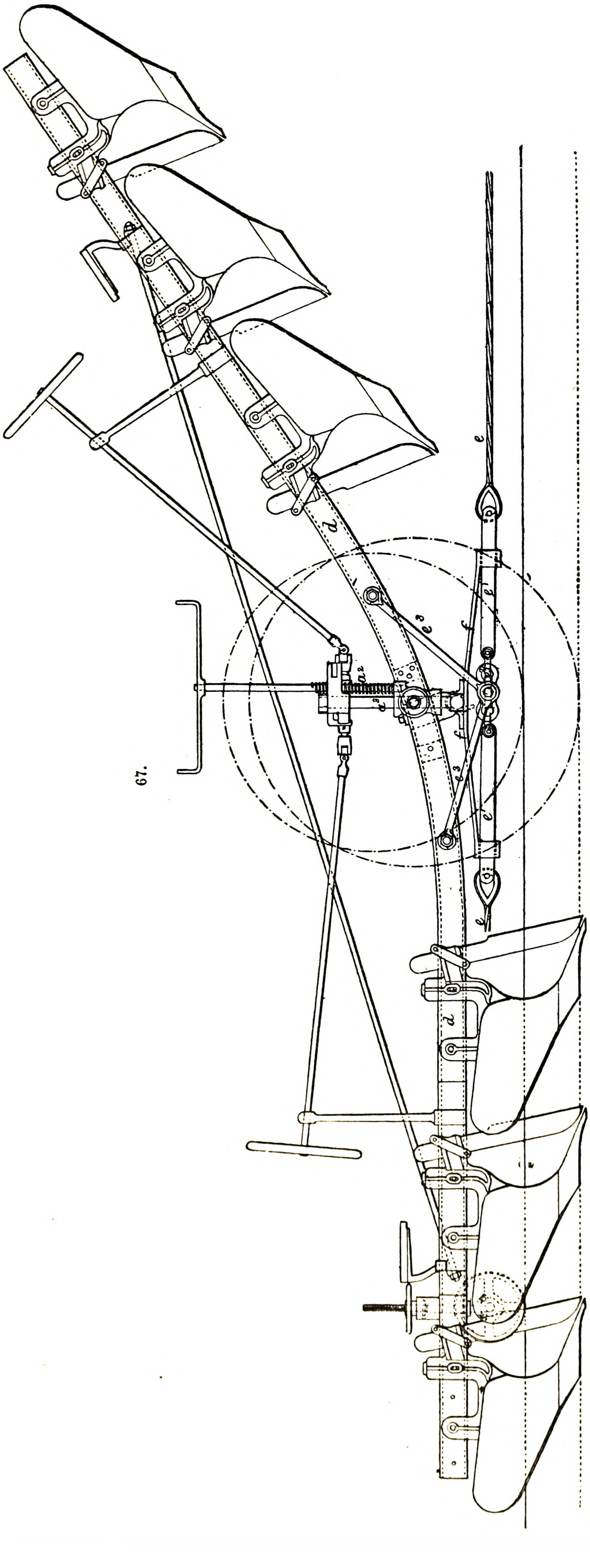

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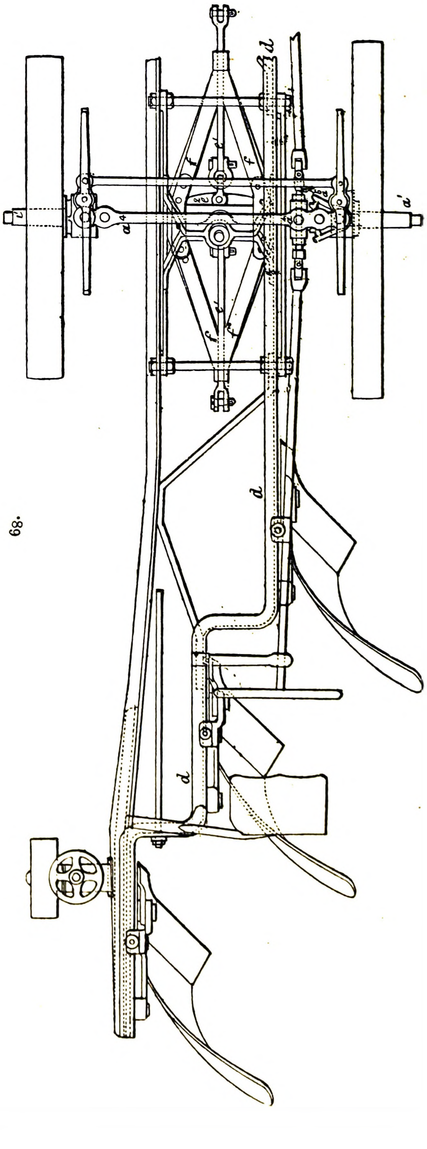
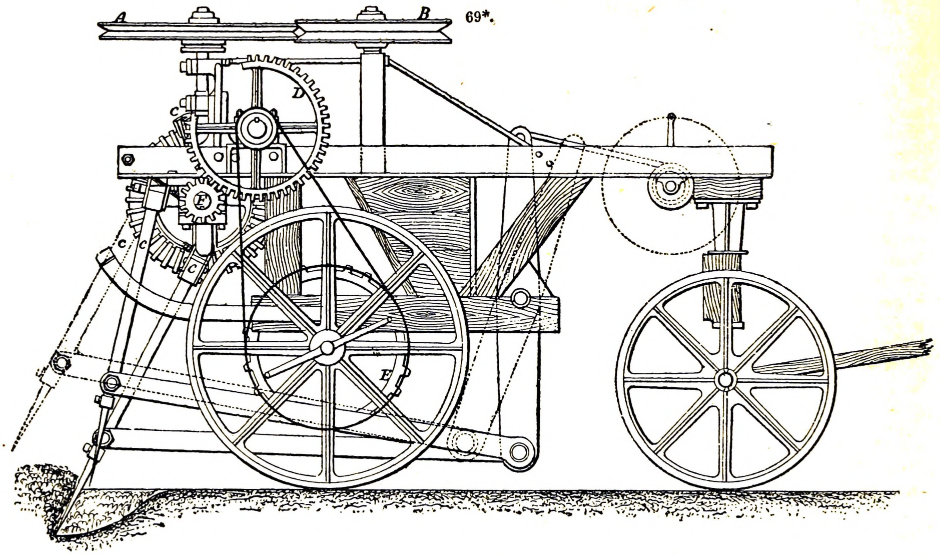


68.

to either end, and works from either side to suit work in both directions, and is self-acting. The coulter is an eccentric disc, and works close to the point of the head, being set to cut an inch or two below the sole of the head and share. In this way, when an obstruction is met, the revolving coulter carries the head over the obstruction. The two land-side rollers or wheels give balance to the implement, and assist in carrying it through gullies or other inequalities of the surface. The two furrow wheels are intended to assist in completing the turning of the furrow after it leaves the mould-board and press it into its position, and otherwise to give balance and guidance to the implement. To each end of the frame, which is a strong trussed structure of malleable iron, is hung, on another centre, a huge plough of ordinary construction, with a long beam of great strength. The object of this is to cut a second furrow from below the first one, and to bring the earth to the top. It is kept down to its work by a loop line of wire rope passing over the plough in connection with the tail and pulling rope. The pull for drawing the implement is taken through this beam, and when required to be reversed the engine pulls the one plough out of work, while it presses the other by means of the looped line into place. The object of having the plough hung on a centre kept in its work by means of the pressure of the tail-rope is to give an elasticity to the working of the implement, so as to allow it to rise from obstructions where these cannot be pulled out. The one end of the implement is a duplicate of the other, unless in as far as the one is right and the other left handed, the implement working either way without being turned.

As balance ploughs were originally constructed, the horizontal pivots of the plough-beam were carried by an inner frame, which was itself connected by a vertical axis to an outer or wheel frame, and on which were the stud-axles for the main carrying wheels. The steering of the implement was effected by turning the wheel frame about the vertical axis, and a handwheel and screw were provided for the purpose. This arrangement was found inconvenient, because the locking of the wheels caused some irregularity in the depth of ploughing. Consequently another system was resorted to, in which the inner frame was dispensed with, and the horizontal pivots on which the plough-beam rocked were carried upon the same frame on which were the stud-axles for the carrying wheels, the steering being effected by movement about a vertical axis imparted to the stud-axles independently of the wheel frame. This arrangement has again been found inconvenient, for that upon rough land an obstacle in the path of one of the wheels is liable to cause the whole implement, including the plough-beam, to be slewed out of its course. Greig, in 1877, introduced an arrangement for the steerage of the implement in a similar manner, but at the same time providing for the free play of the plough-beam about an upright pivot or centre upon the wheel frame, independently altogether of the steerage of the implement. This admits of the plough-beam pursuing its true line of travel, even when an obstacle in the path of one of the wheels may cause the wheel frame to run untruly. Upon the lower bar of the wheel frame is mounted a block, so that it may be able to rock about the bar as an axis; and upon the block is mounted at right angles to the bar a stud or pivot, which enters a socket in the middle of the plough-beam. The draught rope is connected to the plough-beam by draught bars attached to the beam behind the wheel frame and below the centre of the wheels, so that the draught tends to keep the plough-bodies down to the work. The eye by which the draught rope is connected to the draught bars is in front of the wheels, and a guide or stay in connection with the wheel frame sustains it, and keeps it in a central position in respect to the frame, so that when the wheels are thrown out of line by any obstacle the pull of the rope acting on this guide or stay immediately straightens them again. Figs. 67, 68, and 69, are elevations and a section of this plough. a a is the wheel frame, and the stud-axes a^1 a^1 of the main wheels b b are adjustable up and down upon it by means of the screws a^2. The bars a^3 of the wheel frame, on which the blocks carrying the stud-axes slide, are square in section and can be turned; these are connected across the frames a, to cause them to move simultaneously, by the arms a^4 and the bar a^5. a^6 is a quadrant fixed on one of the bars a^3, and a worm a^7 gears with it. This worm is coupled with the axes of the steering wheels. On the lower bar of the wheel frame a saddle or clip c is mounted; it is free to turn upon the bar, and it carries at right angles to the bar the pivot c^1, upon which the plough-beam d is mounted, and about which as a centre, it is able to turn. Upon the plough-beam the plough-bodies are mounted, as is usual in balance ploughs. e e are the draught ropes, connected by the draught bars e^1 e^1 to the transverse bar e^2, which in turn is coupled by the links e^3 with the plough-beam. f is a guide or stay clipped on to the lower bar of the frame a, and having sockets at each end, through which the draught bars e^1 pass. By these arrangements the plough-beam is free to maintain its direction independently of any irregularity in the motion of the wheel frame, which, however, cannot slew without deflecting the hauling rope from its direct course, so that immediately the obstacle causing the irregular motion is passed, the strain on the rope brings the frame round again to its proper position.

Fig. 69* is Knight's steam-power digging machine, specially intended for hop-gardening. The machine is driven by a rope running over the three pulleys, A, B, placed on the top of the implement. The implement is impelled forward and the forks are driven, when required to work, simultaneously. The pulley A is the main driving part, the pulleys B being merely employed to give the rope a sufficient grip. The power is further communicated by the wheel D to the main axle, a notched pulley E and a pitch-chain. There are three forks hung on as many loops of the crank, the loops being at different angles, as shown by the positions of the forks c c c. The upper part of each fork-staff describes a circle with the revolution of the crank, but as the fork-staff is held by an arm one-fourth of its whole length from the bottom, the figure described by the point of the fork is not a corresponding circle, but an oval. By throwing the carrier of the arms forward at the top, the bottom is thrown back, when an oblique instead of a perpendicular thrust is given to the forks. With the forks held in the position of the dotted lines the depth they would enter the soil would of course be less, while the angle at which the spits of soil would be picked would also proportionately differ. The forks may be lifted entirely free from the surface, and for this there is a handle.



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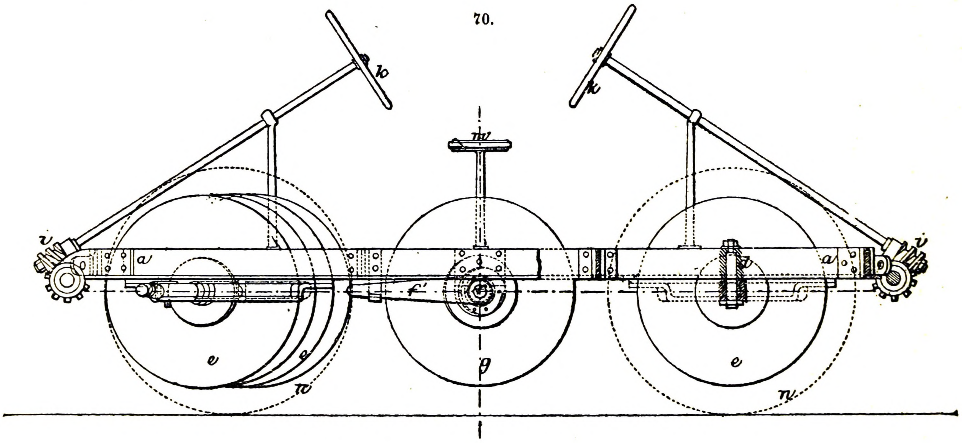
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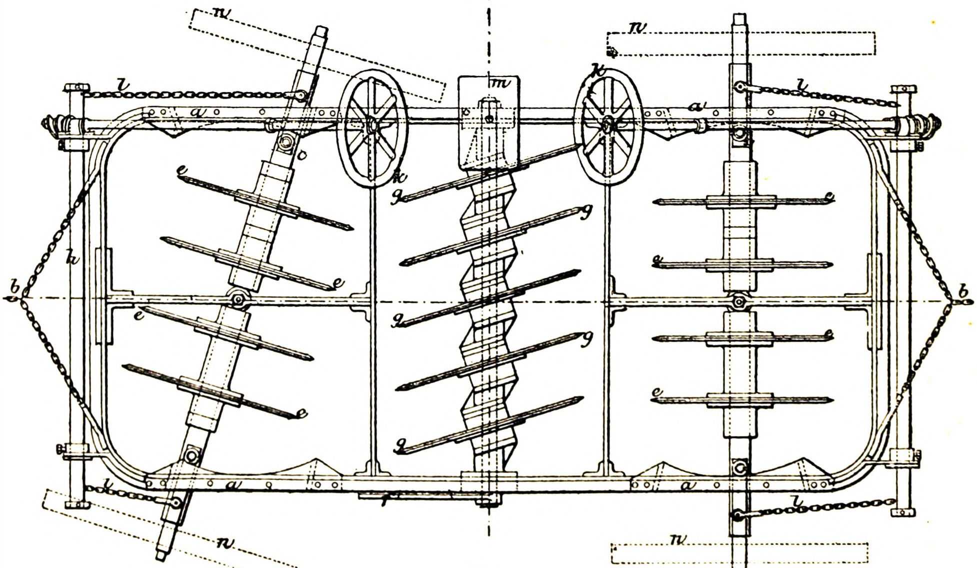
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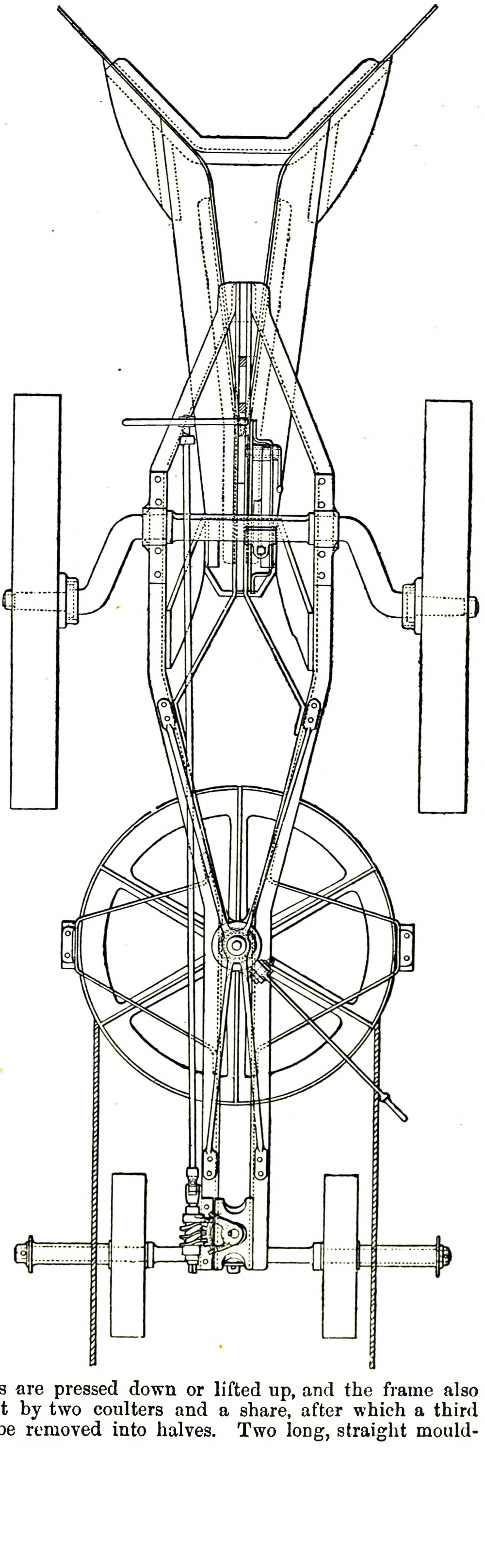
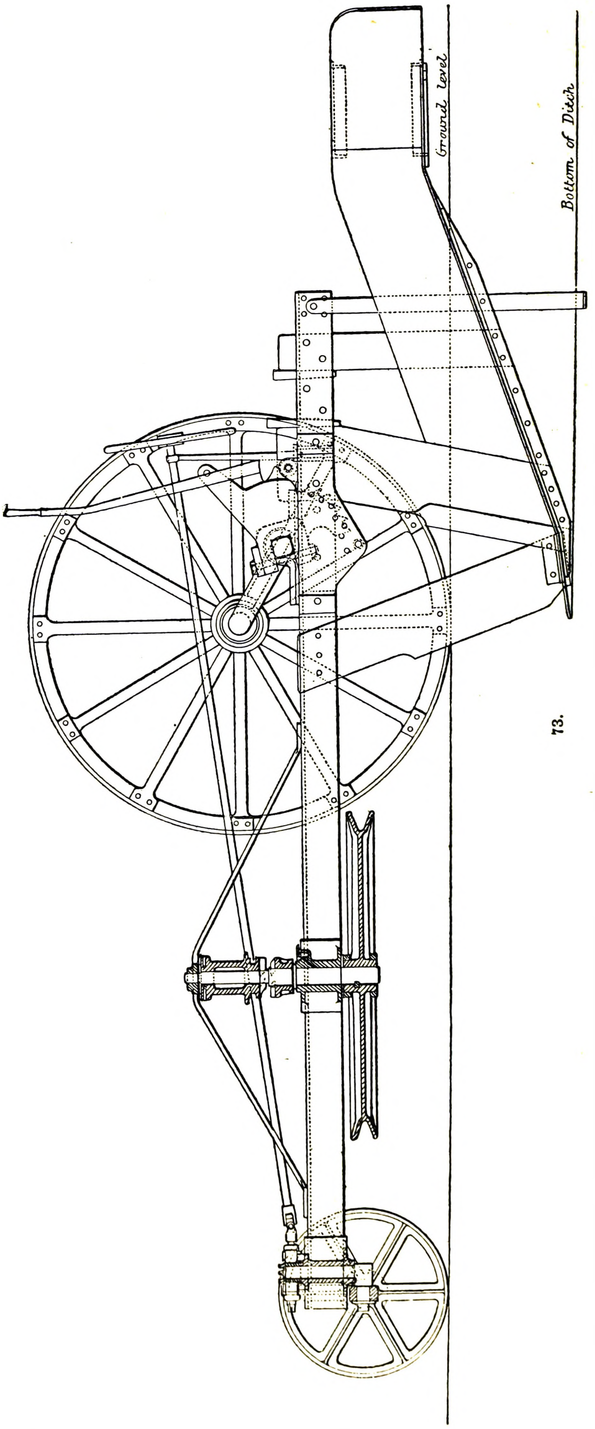
G. Greig's cultivator is intended to be worked by steam power, and consists of one or more series of discs mounted upon an axle and free to revolve. The axle or axles are inclined to the line of draught, so that the discs when drawn through the land, displace and pulverize the soil. In order that the soil may be thrown the same way in whichever direction the implement travels, the axis of the discs is so arranged that it can be made to incline in either direction to the line of draught, or the discs are mounted on eccentrics upon the axis in such manner that by turning the axis half-round, the required change is made in the inclination of the discs. When a furrow wheel is employed, the position of the axis on the frame is changed when the direction of the draught is reversed, so that the leading edges of the discs may occupy the same positions relatively to the furrow wheel in either way of working. If several series of discs are employed, steering gear may be applied, so that the implement may be guided by steering the leading series of discs. At other times separate carrying wheels can be used in connection with the frame of the implement, and steering gear in connection with these wheels.

a a, Figs. 70 and 71, is a rectangular frame to which the draught ropes *b b* are attached; *c c* are axes connected with the frame *a* in such manner that they can turn around the perch-pins *d d*, so as to incline the frame; *e e* are discs mounted upon the axes *c*, so that they can turn freely and independently the one of the other; *f* is an axis carried by the frame between the axes *c*; it has other discs *g* upon it, they are mounted so as to be free to turn upon eccentrics fixed upon the axis, and when desired the axis *f* can be turned half-round by means of the lever-handle f^1 at its end, so as to reverse the inclination of the discs; *h h* are rollers mounted at the ends of the frame *a*, each has a worm-wheel upon it, and a worm *i* engages with the worm-wheel, so that by turning the steering wheel *k*, which is on the same shaft with the worm, the roller *h* can be rotated and made to wind and unwind the chains *l* and to draw the axis *c*, to which the ends of the chains are attached, into an inclined position, and so to guide the implement; *m* is the seat for the steersman. The leading axle *e* and the discs upon it are employed in steering in whichever direction the implement travels, and the hinder axle is set over to incline its discs in a direction opposite to the direction of the discs *g*. The dotted lines *n n* indicate road wheels which are removed when the implement is put to work.

The implement, Figs. 72 and 73, is constructed by John Fowler and Co., of Leeds, for opening wide drainage or irrigation ditches, as required for sugar and cotton cultivation. Near the front end the frame is provided with a rope-sheave, round which the rope from one of the ploughing engines passes, its other end being fixed to the hind wheel of the same engine. Thus the strain exerted by the engine on the implement is doubled. The knife is let in and lifted out of the ground in the following manner. The axle of the hind wheels is cranked, so that in turning it the wheels are pressed down or lifted up, and the frame also either raised or lowered. The ditch is cut by two coulters and a share, after which a third central coulter splits the mass of earth to be removed into halves. Two long, straight mould-


72.

boards conduct the earth upwards, and deposit it on both sides of the finished ditch. Ditches of $1\frac{1}{2}$ to 2 ft. in depth can be made with this implement at the rate of a mile an hour in suitable soil.



73.

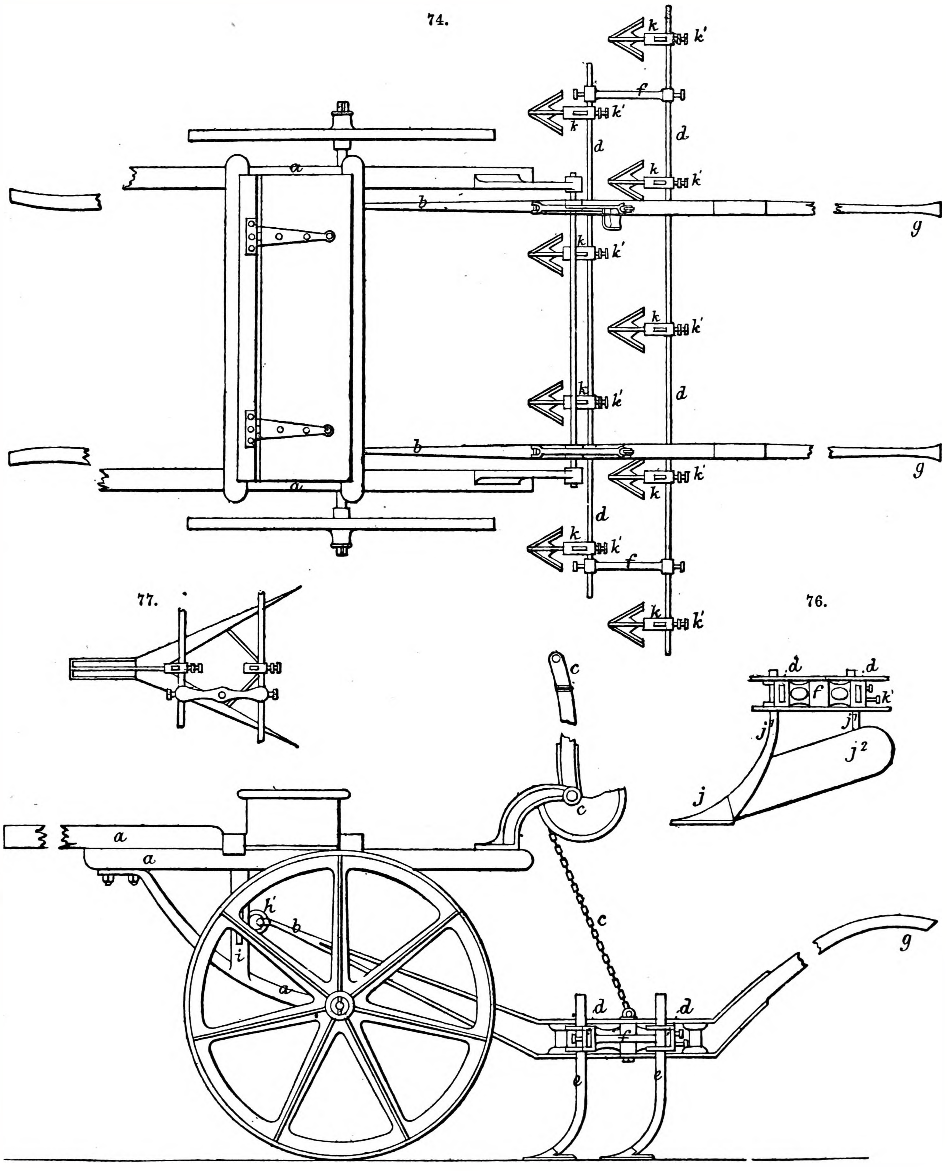
Fig. 74 is a plan, and Fig. 75 a side elevation of a general purpose steerage horse-hoe or ridger by Headly, Hill and Warden. It is made with a fore-carriage *a* and steerage *b*, and fitted with a lift *c*, to raise the hoes out of work at land's end, and enable the machine to be moved from place to place without detaching any portion of its mechanism.

The horizontal bars *d*, which carry the hoe-standards *e*, slide through two cross heads *f* and through the steering handles *g*, giving great facility for moving the hoe-standards to the usual, or any particular width of cropping.

The steering handles *g*, are hung upon a horizontal draught-bar *h*, in front of the fore carriage. This draught-bar can be adjusted to any width, by shifting the eyes or loops h^1 in the slots, and fixing them in the required positions by lock-nuts; and by raising or depressing the draught-bar in the slots *i*, which is effected by lock-nuts, the depth and evenness of hoeing can be arranged at pleasure. Ridging or moulding plough-bodies, Figs. 76 and 77, which consist of pointed or winged shares *j* fitted to heads or stems j^1, carrying light movable steel, iron or wood mould-boards j^2, are attached to the horizontal bars *d* by means of the usual clips or fastenings *k* used for securing the hoes, the clips *k* having two set-screws k^1, thus avoiding the possibility of any lateral movement of the implements when in work.

Any of the usual forms of this implement may be applied to potato-raising, by attaching several grids or bars of openwork to the ridging heads or stems j^1, and an additional tail-piece or set of prongs to end of slipe, so as to thoroughly separate the soil from the potatoes; by this means several rows can effectually be lifted at once.

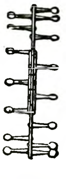
Mechanical Sowers.—In any agricultural country the quantity of seed sown is so enormous that the smallest economy, either in the labour of sowing, or in the seeds sown, represents an important annual value. This fact has been fully appreciated, and the improvements in drilling and sowing machines are only outnumbered by the attempts at improvement. The first process of sowing in all countries is the ancient one of "sowing to the wind" by hand, or hand-sowing. Simple as the operation appears, it needs practice, a certain ability, and attention; and a good double-hand sower will disperse the seed from either hand with equal facility. But experienced as the sower may become, hand-sowing cannot compete in precision and accuracy of placing the seed with machine-sowers. The hand-sower, moreover, leaves the grain he throws into the ground uncovered by soil, and the operation of covering soil over the grain must be a separate one in which the field traversed by the sower must be again worked. With the sowing machine, the preparation of the



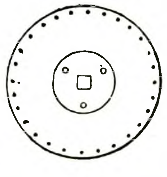
74. 77. 76. 75.

earth to receive the seed, the sowing of the seed and covering it are operations performed with practical simultaneity. Certain mechanical sowers mix the grain with a proper proportion of liquid or solid manure. The necessity of working equally well on rising ground as horizontally adds to the difficulties attending the construction of a sowing machine, and the conditions to be fulfilled are sufficient, notwithstanding the numerous machines introduced, to reduce those practically successful to a small number.

78.

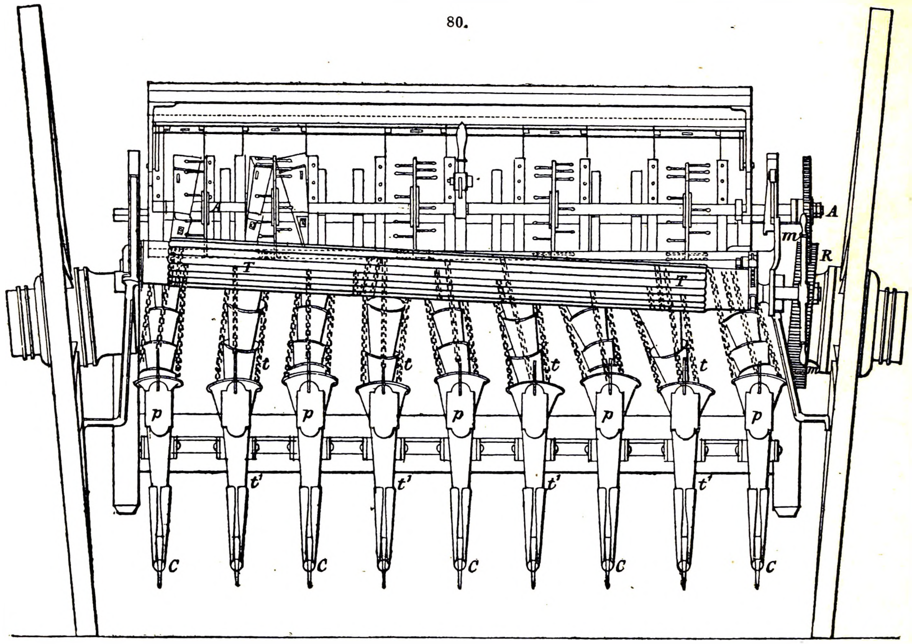


79.

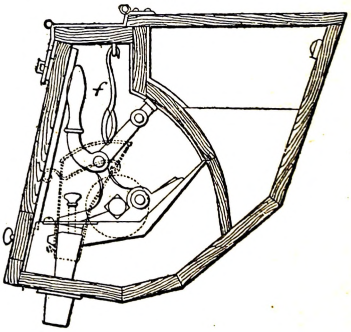


Spoon Drills.—The machine which we illustrate may be taken as a type of this kind of drill or sower. The grain-distributor consists of a series of small spoons, Figs. 78 and 79, of dimensions proportional to the size of grain that they are to hold, the shanks of these spoons being set perpendicularly to the plane of a sheet-iron disc. This disc is mounted on an axle which receives its rotative movement from gearing R, Fig. 80, mounted on the wheels carrying the machine. The velocity of rotation of the spoon-disc is therefore proportional to the space traversed by the drill. The spoon-disc revolves in a wooden box with concave bottom, constantly fed with grain by a hopper placed at the side and slightly higher, Fig. 81. Each spoon arrives in turn at the lower part of the box and fills itself with seeds, which it raises and throws into a funnel arranged to receive them. This funnel communicates with a series of flexible tubes, which the seeds traverse in order to arrive at the part of the machine that introduces them into the soil. This part of the machine is very simple, very strong, and constitutes the trait characteristic of perfect sowers. It consists of a kind of coulter C, carrying at its hinder part a larger drill in connection with the tube t^1 supplying the grain. This coulter opens the sufficiently mellowed soil to a certain depth, it allows the grain to fall to the bottom of the trench that it makes, which it closes by allowing the earth to fall in. The distributor and the share are the essential parts of the drill. The spoon-discs are put in motion by the gearing R, and each revolution or fraction of a revolution of the wheels corresponds to the emptying of a certain number of spoons into the funnel, and so to the arrival in the soil of a certain number of seeds. When the machine stops, the distribution of the grain stops also, and it is impossible for the grain to be delivered in excess. The equality in depth at which the seed is buried is obtained by a very efficacious arrangement. The coulter is mounted on a jointed lever, sustained at its other extremity by a chain wound on the whim T T, and raised or lowered at will by the handle *m m*. If the chains are so raised that the coulters are above the earth, as shown in the figures, the machine does not work, and may thus be transported along roads. The weight of the coulter and of the lever which supports it is regulated in such a manner that it enters the soil to a depth fixed by the position of the whim and by the free length of chain. If the soil offers more resistance than ordinary soil, or if the depth is above the average, weights are placed at the end of the lever. If the coulter encounters an obstacle or a portion of the earth accidentally higher than the rest, it raises itself by turning around the centre O and falls as soon as it can retake its normal position. Tubes of caoutchouc have been proposed as substitutes for the funnel-tubes t^1, but these afford greater freedom of action. All the spoon-discs are mounted on the same axle parallel to the axis of the hopper which contains the seed. This axis should be very nearly horizontal, even when the machine works on earth inclined to the right or left. This result is obtained by putting cast-iron wedges under the axle of the hopper. It is necessary that the grain-box and the funnels into which the spoons are emptied should always preserve the same relative vertical position when the machine ascends or descends a declivity. A screw, commanded by its handle, obtains this result. The small hammers *f*, Fig. 81, raised by the shanks of the spoons, strike the funnels and impart to the whole system a slight vibratory movement intended to prevent fine moist grain from adhering to and hindering the action of this part of the machine.

80.



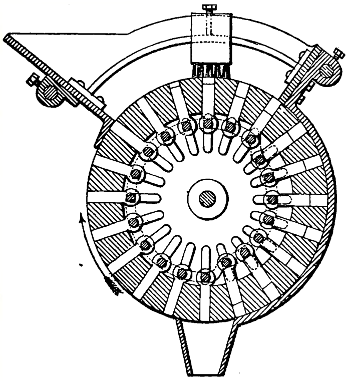
81.



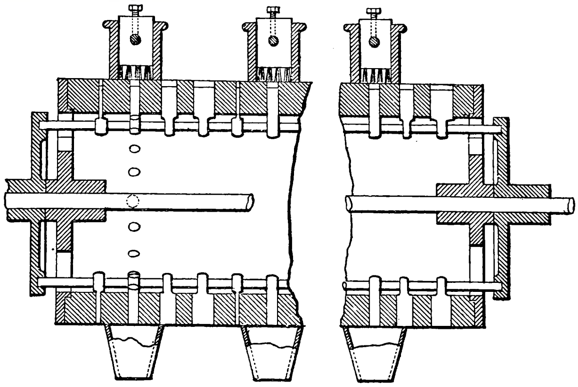
Kipping's drill includes a travelling surface provided with recesses of suitable magnitude for receiving the particular seed required to be sown, and in the desired quantity, this surface constituting the bottom of a hopper and being provided with pistons which move in recesses.

Figs. 82 and 83 represent the operating parts in transverse and longitudinal sections. A cylinder fixed upon a shaft is caused to revolve. In Fig. 83 this cylinder is broken off at the middle, but along its length are groups of perforations of different sizes, suitable for various sizes of seed, for turnip, for instance, and for beans, the intermediate sizes being suitable for wheat, barley, or other grain. Within these perforations are pistons, the inner ends provided with loops strung upon bars, the ends situate in grooved cams, through which the shaft passes loosely, the cams being fixed, so as not to revolve, to the framework of the drill. The configuration of the grooves is shown by dots in Fig. 83, and slots are formed in the ends of the cylinder which act as guides for the rods; a hopper, the bottom of which is constituted by the cylinder, being mounted so as to slide upon rods carried by the framework. To this hopper is attached a guard extending downward along the circumference of the cylinder and terminating in a spout. Within the hopper is a rod, curved so as to correspond with the circumference of the cylinder, and upon this rod is a brush, which may be tightened in any required position by a set-screw. Fig. 82 shows the recesses and one row only continued around the circumference of the cylinder, but the others are disposed in like manner, and the pistons are omitted except where the section is taken. The action of the apparatus is as follows;—It being assumed that the cylinder is caused to revolve in the direction of the arrow, and that seed is fed to the hopper from a main hopper, in any ordinary manner, it requires to be measured and distributed by means of the rings of recesses; the description, however, will refer to the sowing of one row of grain only, into a furrow made in the usual manner by a coulter. As soon as the revolution of the cylinder has carried the recesses into the hopper, the shape of the cams draws the rods downward, and the pistons, which before this have filled the recesses, partaking of that motion, cavities are successively formed, into which a certain number of seeds pass, the brush sweeping off the superfluous quantity. As soon as a recess passes the brush, the shape of the grooved cams draws the pistons farther downward, so that when the recess reaches the guard, the measured quantity of grain has a superfluity of space, the object being to prevent the loss of grain. When a recess has passed the guard, the grain is free to fall through the spout. The grooved cams then quickly project the piston, to ensure emptying the recess, the piston also serving to clear away any dirt that may have been taken up. The grain thus delivered to the spout is conducted to the furrow by the usual means. This description has referred to the sowing of one row only, but the cylinder has as many groups of recesses as there are rows to be drilled, each group having its hopper and brush, Fig. 82; and in order to use this hopper for any one of the rings of recesses, according to the size of the seed, or the quantity to be delivered at a time, the hopper is made to slide longitudinally on rods. The brushes are mounted on the curved rods, for the purpose of shifting them backward or forward, so that the quantity of seed which passes into the recesses may be varied.

82.

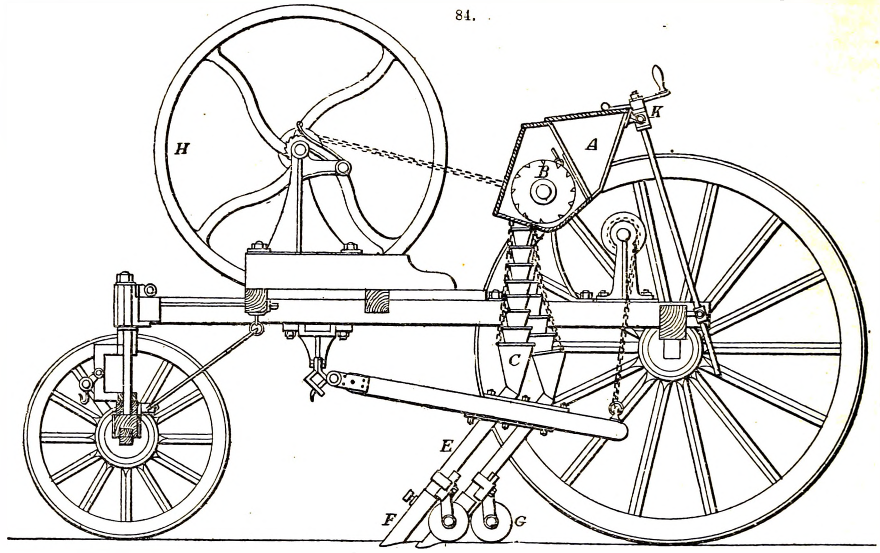


83.



Tooth's plough drill was designed for the purpose of improving the natural pastures of New Zealand. The first machine was built by Garrett and Sons in 1865, and has been in almost constant use at Alford, New Zealand. The seed is contained in the box A, Fig. 84, whence it is delivered by the cup barrel B, driven off the travelling wheel by a chain having two changes of speed, into the telescopic pipes C, leading to several levers, into which are keyed stout wrought-iron pipes E, upon which the shoes or shares F are fastened by set-screws. These shoes are of steel, hollow and chisel-pointed, for cutting into the ground and overcoming the tussocks, roots of trees, and other obstacles. The depth of the furrows is regulated by fastening the discs G higher or lower on the pipes E, by means of cramps. The seed is deposited through the shoes F, in the bottom of the grooves or furrows cut by them, and the ground is then pressed and consolidated over the seed by the rollers G. The wheels are much higher and stronger than those of the ordinary drill, and the whole machine is specially adapted for rough usage. It is drawn by two horses, the driver riding upon the top of the box, whence he is able to watch the action of the levers, to wind them up or lower them as necessary, by means of the large fly-wheel H, which communicates by sheaves and chains with the winding barrel at back of drill, and to regulate the position of the box, to suit hilly or uneven land, by means of the regulator K, which is similar in principle to that in ordinary corn drills. The framework in front of the driver is arranged as a platform, upon which sacks of seed, to replenish the box when drilling very large areas, can be laid. The distance between the rows can be regulated in the usual manner in drills, by altering the number of levers used. The levers are easily shifted, fixed on or taken off the arras bar, by a joint containing one bolt and nut only. The levers are made fore and aft, in order that they may not be choked. In passing through the tussocks, the fore shoes are clear of the obstacle before the after ones encounter it. This machine, by means of the wheel running behind the shoe, regulates the depth at which the seed should be deposited, a point of great importance in sowing small seeds.

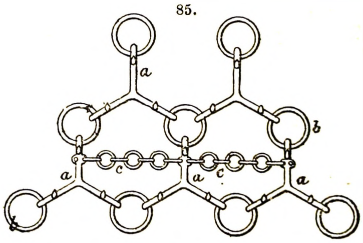
84.

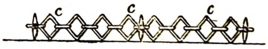


Harrows.—The harrow effects on a large scale the purposes of a rake, and usually consists of a number of rough points, or spikes, fixed in a frame. The tripod-pieces of harrows as ordinarily constructed, when put together for work, leave open spaces between them, but in Howard and Bousfield's Sommerton harrow, Figs. 85 and 86, these spaces are divided up by links which are suspended from the tripods, and serve to act upon the ground, greatly adding to the efficiency of the implement.

In the Figs., *a a* are the tripods made of cast iron, and connected together as usual by means of rings of wrought iron *b*. The spaces enclosed by these tripods are divided up by means of links *c c*.

85.

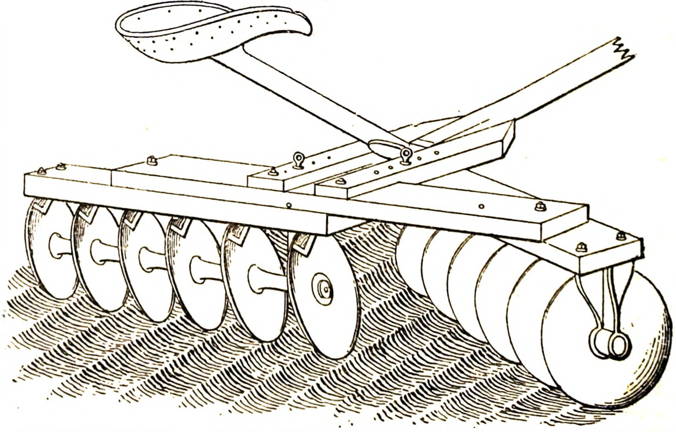




86.

Randall's Pulverizing Harrow.—In treating farm lands reclaimed from turf or peat-bogs, there was at one time great difficulty in reducing the furrow of turf after the plough; ordinary harrows often failed to penetrate it, and it had to be chopped up by hand-power. A great advantage has been obtained from the use of Randall's pulverizing harrow, an American invention, Fig. 87. Beneath the bar to which the shafts are attached, there are two frames, each carrying six sharp-edged revolving discs, so arranged that they can be set obliquely at any angle to the line of draught. The discs are not plain but are slightly dished, the concave side being inwards. Each disc cuts into the furrow, and pushes the strip it has cut towards the centre of the machine. Whenever the furrow is tough, the weight of the driver increases the cutting-power of the harrow. The work done by this machine is of great service in comminuting turf and peat. When the bog is not firm enough after draining for ploughing, it must be dug by hand and thrown up in ridges or lazy beds, 4 ft. wide.

87.



Reapers, Mowers, and Harvesters.—Fig. 88 represents Wood's self-delivery reaper, and Figs. 89, 90, and 91, detached pieces of the mechanism. Fig. 91 shows the method of communicating rotating motion to the reel-shaft from the main bearing or driving wheel, through a pinion gearing into teeth on the inner face of the wheel. *a* is the shaft upon which the pinion is fitted; it carries at its outer end a worm *b*, the blade of which engages between the rollers *c*, on a horizontal disc or plate *d* for turning it. The axle *e* of this disc passes through a support *f*, to keep it in a vertical position, and also through a cam-block *g*, the face of which is of peculiar shape, to compel the rake *h*, and reel-arms *i*, to rise and fall to follow the work. The upper part of the axle carries a hood *j*, furnished with lugs *k k*, through which the pins of the arms *h h* and *i i* pass. These form the joint-pins for the arms, and also serve to carry them round with the hood, which is keyed upon the axle, Figs. 89 and 90. The cam-block or plate is held in place by a bracket *n*, bolted to a brace *o*, the distance being maintained by the height of a socket or pillar *f*, which is also bolted to the brace *o*. The brace is centred at its ends upon brackets, springing from the side beam of the machine. Its purpose is not only to support the hood and the parts in connection, but also to enable the axle with its appendages to be tilted, so that the rake-arms can pass obstacles; and for this a foot-beam *q*, is attached to the top of it. The cam-block *g* only lodges upon the socket or pillar *f*, and its position is governed by the length of the curve given to the strap *n*. By this means the block can be shifted round upon the socket, and held firmly at any part, for throwing the rake and reel blades into work, in advance of, or behind, or over the points of the fingers, and also to rise clear of the platform. The block or cam is so made that a portion of the working face is at the edge, and a portion under the edge, these portions being at different parts, so that the rake or reel arm, in passing over the platform, is not allowed to rise or to drop any of the grain. The arms are arranged in pairs through rods or links, and this coupling permits the vertical arm to find an abutment against the edge of the cam-block. The depression of the foot-plate enables the attendant to lift the rake-blades, so that they act as reel-blades only when passing over the platform, and allow the grain to accumulate upon the platform until there is sufficient to form a sheaf, when he can remove his foot and allow the next rake to sweep the grain off. By this arrangement, where the crop is very light or thin, he can so time the delivery that the grain deposited shall at all times be sufficient to form a sheaf. Where the grain is heavy or thickly grown, this will not be necessary, as the rake-blades will act in regular order, and deposit behind the track at fixed distances. Each of the rake-blades is fitted at one end with a bolt or pin *s*, so that they can move upon them, and a bar or link *t* is secured to the other end. This is provided with a number of slot-holes, for raising and lowering to suit the height of the grain, and to act upon the grain nearer to or farther from the ears; the bolts or pins pass through plates on the bars. About the middle of the knife-beam is fitted an elongated finger *w*, with a curved top face for the rake-blades to ride up should they descend too low, and to prevent the teeth coming foul of the knives, and an iron strap is fitted between the two teeth, to prevent the blades being injured. In Fig. 88 only one main bearing wheel is shown, and this is composed of a band with teeth in the inner periphery, for the teeth of the pinion to gear into, and with two rings placed vertically and held in position by tie rods, on which rollers are mounted for bearing against the base rim of the teeth, one of these rollers being toothed, to act as the pinion for transmitting the motion to the knives, and also to the reel-arms, if the machine be a reaping

88.

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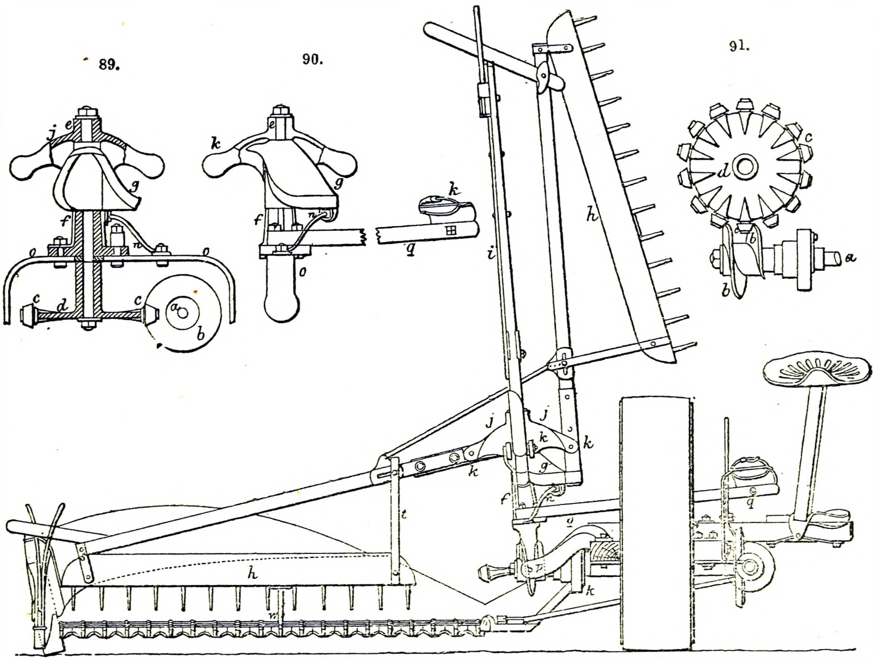
91.

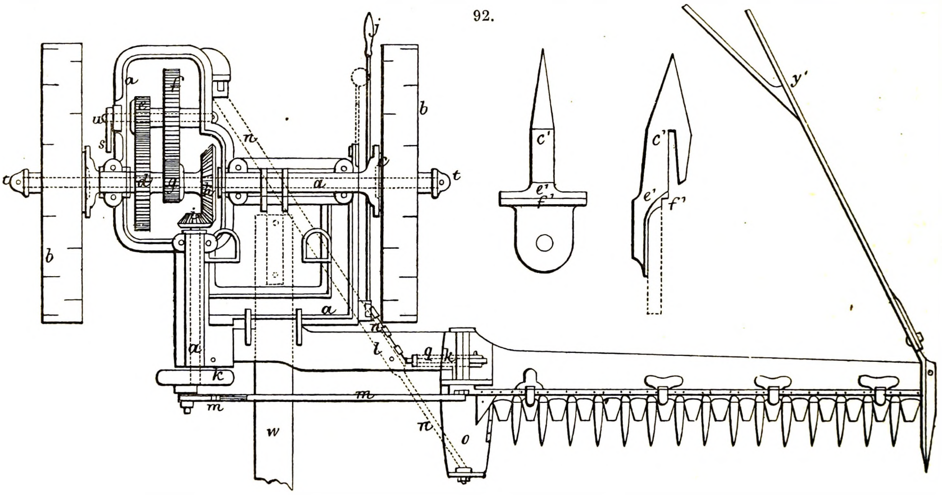


machine, or a combined reaper and mower. The band wheel is held between the frame by the vertical rings, and the height for cutting can be regulated by a pin. The wheel has no spokes, and the connecting rod can be passed through it, so that the bevel gearing for actuating the knives can be upon the outside of the framing, and the cutting take place in a line with the centre or axis of the wheel, so as not to interfere with the draught or pull of the horses. There is a peculiarity in the rising and falling motion of the machine when the wheel is employed, and that is that the platform is not canted, or brought lower, at one end or side than the other, because the fixed pin *a*, or axle of the rings, forms the fulcrum at all times, and movement imparted to one point is instantly communicated to the whole of the machine. The platform and framing always form one plane with the horizon, at whatever height they may be moved by the lever at the back, when passing obstacles. The tilt of the platform for angular cutting, is obtained from the position of the adjustable nut upon the front cross-bar. Swivel blades are fitted at the tips of the rake and reel arms, to ride over the platform ridge, to prevent the entanglement of the ears of the grain, should they droop in the direction of the platform. Reciprocating motion is communicated to the knives only when the machine is travelling in the forward direction, and for this purpose, a kind of box on the axle is arranged, in which a series of ratchet teeth are made for a pawl to drop into, the pawl being kept in action by the spring, the pressure of which is overcome by the pawl riding over the teeth if the machine is moved backward.

Kearsley's Mowing Machine.—Figs. 92 to 98 show various details of one of several varieties of mowing machines manufactured by H. and G. Kearsley, of Ripon.

The form of the frame, which is of iron, is seen in the plan, Fig. 92, from which also the arrangement of the motion will be understood. Upon the axle of the travelling wheels of the implement is keyed a spur-wheel gearing into a pinion, cast in one piece on a spur-wheel which runs on a movable stud, and allows the motion to be thrown in and out of gear by an eccentric lever. The spur-wheel last alluded to gears into a pinion on the main axle, and cast in the same piece with it is a bevel wheel, which drives the bevel pinion keyed on the crank-shaft of the implement. This gearing is enclosed in a casing, which protects it from dirt, and also serves as a guard to prevent the entanglement of the reins. The lifting apparatus consists of an ordinary lever and chain, attached to a quadrant that is fastened to the joint-bar by a double stud and bolt. A short slotted

92.



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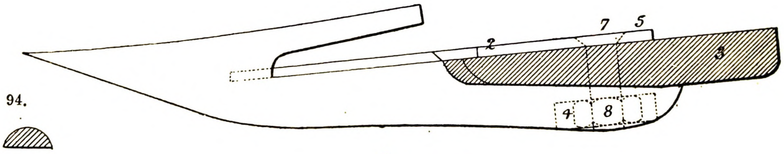

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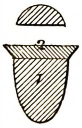

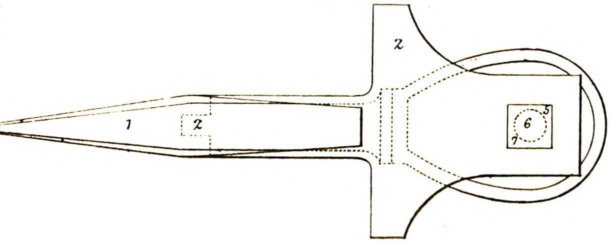

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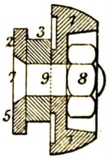
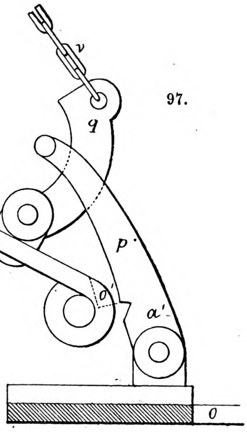
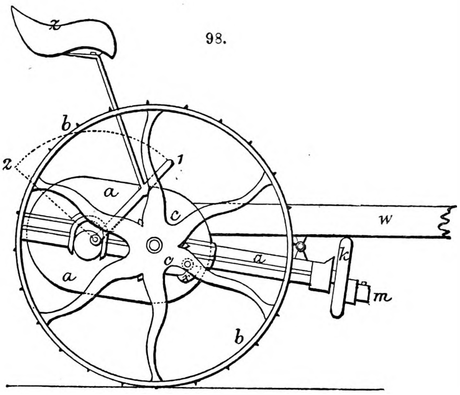
96.



lever is fastened to the joint-bar by a bolt and stud, and in this lever is a notch, there being a corresponding notch in the end of the joint-bar, which forms a fulcrum for the lever to work upon. The quadrant passes through a slotted lever, and thus, if the outer end of the guide-bar is in a hole, the driver can raise it to a level position, as soon as the inner end begins to move, and by the same means the finger-bar can be raised high enough to clear obstructions in the field. The guide in which the knife works is formed with a step, next to the finger-bar, in order to increase the slanting edge under the guide, and prevent the accumulation of dirt under the knife. Thus the spur-wheel *d*, Fig. 92, is keyed to the main axle *t*, and gears into the pinion *e*, cast in the wheel *f*, and running on the stud *u*. This wheel gears into the pinion *g*, on which is cast the bevel wheel *h*. The pinion *i* is driven by the wheel *h*, and on the other end of the shaft is the crank-disc *k*, to which is attached the end of the connecting rod *m*. In this rod is a tube containing oil, and at every revolution of the disc *k* a quantity sufficient for lubrication is liberated. The other end of the connecting rod is attached to the knife-bar. The dotted lines *n n* show a stay or support secured to the frame *a* at the back of the implement, and to the finger-bar *o*, and joint-bar *l*, to keep the frame in position. The lever *j* is pinned at *n* on the frame *a*, which carries the crank-lever, and to which is attached the chain *v*, and the quadrant *q*, which passes through the slotted lever *p*, Fig. 97, attached to the finger-bar, the quadrant being connected to the joint-bar. This is the lifting arrangement. For stopping or starting the implement, the lever *s* is employed, having at its lower extremity an eccentric working on a stud *u*, on which the wheels *e* and *f* revolve. This is effected by moving the lever from 1 to 2, Fig. 98, as shown in dotted lines. The guide in which the knife works is shown at *c'*, and the notch already mentioned is at *f'*. This forms part of the guide for the knife to work in. The slanting edge *c'* prevents the accumulation of dirt upon the guide. Figs. 93 to 96 also show the manner in which the Kearsleys form the fingers of their implements. The fingers 1 are made in the ordinary way, but in the bottom is formed a recess 4, and on the top is placed a steel lining 2, secured to the finger-bar 3, by the bolt 6, the squared head 7 of which lies flush in the recess 5, the same bolt on the other side being secured by the nut 8 in the recess 4. The front end of the steel lining is made with a tongue that fits into the recess shown on the top of the finger-bar. The advantages claimed by this arrangement are, that there are no projecting nuts to offer any resistance or obstruction, or around which the cut grass can gather.



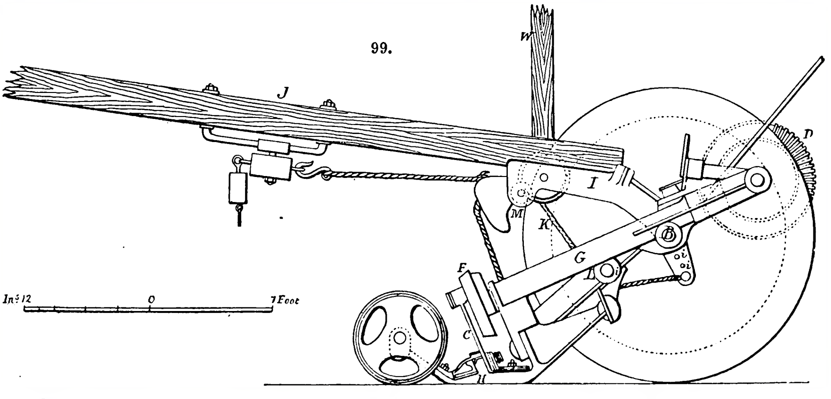
97.



98.

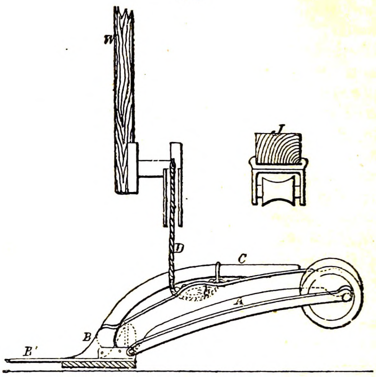
Figs. 99 and 100 illustrate Samuelson's two-horse mowing machine. The two most important features of this machine are, that the horses in drawing tend to lift the knife off the ground, and so when the resistance is increased, as by the knife taking a mole-hill, this tendency operates to relieve the machine and reduce the draught, and the second feature is that when lifted, the point or outer end of the finger knife-box rises first, while in other machines it rises last. Fig. 100 shows the extension bar of the mower. A is a portion of the main framing of the machine, to which the

99.



shoe B, carrying the finger-bar B′, is hinged. W is a wooden lever for lifting the finger-beam when required. Jointed to the shoe B at a point in advance of the hinge joint, is the extension bar C, to the free end of which is attached a chain D, which passes round a half-pulley *b*, mounted in the side frame A. So long as the chain remains loose the finger-beam will be free to play upon its hinge; but when tension is put on the chain the free end of the extension bar C will be drawn down, and the arm will then come into contact with a projection formed on the shoe B. Upon this projection the extension bar C will bear as upon a fulcrum, and will act as a rock-lever, thereby stiffening, and at the same time raising, the finger-beam. Fig. 99 illustrates the draught chain K, and the travelling wheel, to the axle B of which the main frame of the machine C is pivoted. D represents the bevel gearing employed to give motion to the crank-wheel F, and through that and the connecting rod G, to the cutting apparatus of the machine, which is placed at H. I is the pole or drawing bracket, which is also pivoted to the main axle B. To it the pole J is secured. The pole-bracket is made of such form that the draught chain K can be attached to it, and adjusted at *i*, below the centre of the axle. The chain passes from the tail of the bracket I under a pulley L, mounted on the main frame below the main axle, and over or through a guide M, carried by the pole J. The pole J serves simply to guide and turn the machine, the whole of the draught being carried through the chain K, to the forward end on which the whipple-trees are attached. By varying the vertical distance of the point of attachment *i* of the chain, or the position of the pulley L with respect to the main axle, or by adjusting both of these with respect to the main axle, the tendency to lift the beam or pole, or both of them, may be varied as desired, and all weight and pressure taken off the horses' necks.

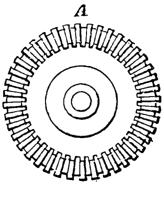
100.



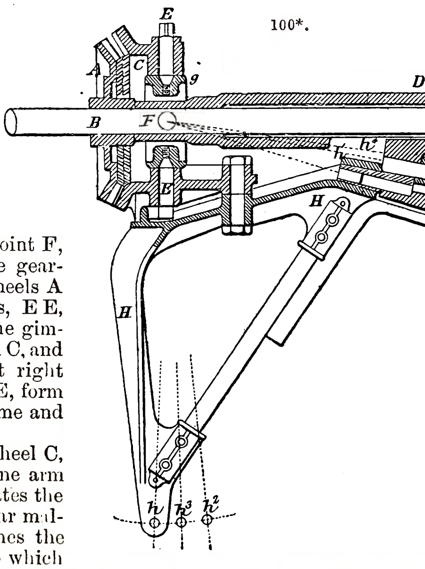
In the mower of Otis Brothers and Co., of New York, the motion is transmitted from the travelling wheels to the knife by a single pair of bevel wheels, and much friction is thereby saved. Figs. 100* to 102 illustrate this gearing.

The driving wheel A is keyed to the main axle B, and revolves with it. The oscillating internal bevel wheel C, is pivoted by a gimball joint to the sheaf or frame D, in such a manner that it can swing round the point F, which is the apex of the gear-cone of the two bevel wheels A and C. Two steel pins, E E, form the joint between the gimball ring *g* and the wheel C, and two other steel pins, at right angles with the pins E E, form the joint between the frame and the gimball-joint ring.

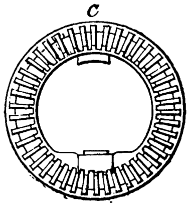
101.



100*.



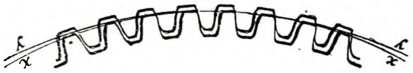
The internal bevel wheel C, thus secured, serves as one arm of the lever which operates the knife, while the triangular malleable frame H, furnishes the other end of the lever, to which the link which operates the knife-head is attached at *h*, whilst the other end of h^1 furnishes a bearing for the guide-crank I. This guide-crank is shifted to one side of the main shaft, and the centre-line of the shaft, as well as the centre line of the crank-pin, and the centre-line of the four joint-pins, radiate from the point F.



102.

When the gear-wheel A revolves with the main axle, it causes the bevel wheel C to swing on the centre of the gimball joint, whilst the guide-crank I is turned in the opposite direction to the main shaft. Whenever the guide-crank I has made one revolution, C has been in contact with all the teeth of A; and as C has 48 teeth and A only 46, it has passed over two more teeth than A; and when the revolutions of the guide-crank have gone on twenty-three times, the same teeth of both wheels will be in contact again. Thus, for every revolution of the gear-wheel A, there are twenty-three revolutions of the guide-crank; and during this one revolution 1048 teeth have been in contact. But although the guide-crank makes a rotary motion, the oscillating wheel makes a vibrating motion on the gimball-joint pin, and the arm H, which is in reality a part of the wheel C, makes at the point h a reciprocating motion from h to h^2, which corresponds with the angle formed by the crank-pin when in the position shown in Fig. 100*, and the position of the crank-pin, when the guide-crank has made half a revolution. We have thus a double lever, which is pivoted to the frame at F, to which the knife is attached at h, while the gear-wheel C is the other end of the lever. When the teeth of the two gear-wheels A and C are in contact, the point h is at a standstill, and the knife is at one extremity of its stroke. But the forward motion of A will bring all the teeth of C successively in contact; and when the guide-crank has made one-quarter of a revolution, the point h has reached the position h^3; and when half a revolution has been made by the crank, and the centre of the crank-pin is in the position shown by the line at h^4, the arm has reached the point h^2, and the knife-bar has made a stroke in one direction. The next half of the revolution will bring the teeth of C in contact with those of A on the opposite side; and this causes the arm to move back to its original position, and the cutter-bar has completed one motion. The rotary motion of the gear-wheel A, is thus converted into a reciprocating motion in the most direct manner, and without any further loss by friction than what is due to the vibration of the wheel C on the gimball joint. The guide-crank performs the function of a balance wheel also, and the motion of the point h is identical with the motion produced by an ordinary crank and pitman. To produce one vibration of the cutter-bar, the forty-eight teeth of the oscillating gear come in contact with the teeth of the driving-gear wheel, and of these teeth at least six are in contact all the time. Thus the wear is evenly distributed.

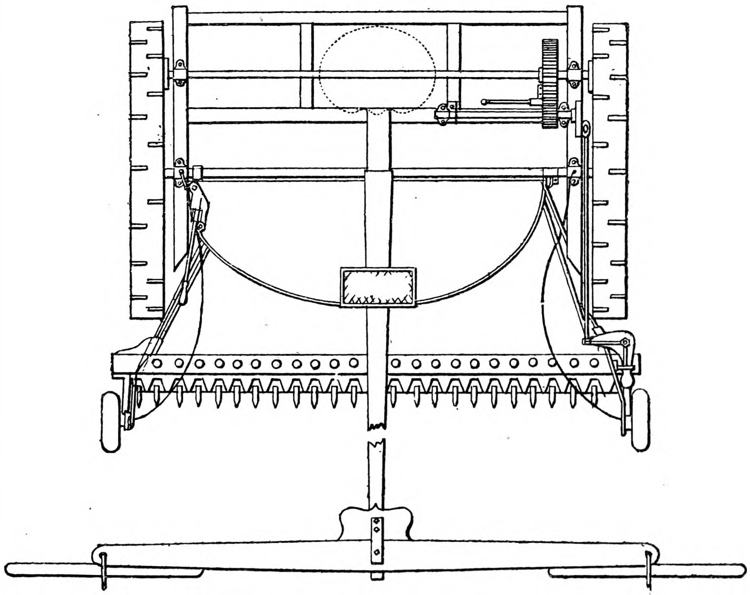
In Fig. 103 the teeth are shown: $x\,x$ represents the pitch-line of the driving wheel A, whilst $y\,y$ represents the pitch-line of the wheel C. It will be evident that the rotary motion of the driving wheel is converted into a reciprocating motion, and transmitted to the cutter-bar by one gear-wheel, without the use of two, and sometimes three, intermediate shafts. Forty-eight teeth are successively in contact to produce one vibration of the cutter-bar, whilst in the ordinary gear only $\frac{1}{23}$ of the number of teeth of the driving gear can be used for each vibration. Using the whole periphery of the driving wheel for each vibration, and having so large a number of teeth in contact at once, allows of the gear being reduced to one-third the ordinary size, with three times the working surface. The cutter-bar of Otis Brothers' mowing machine is attached to the arm of a lever pivoted to the frame, 24 in. long, whilst the driving wheel A operates upon an arm of the same lever, which is $3\frac{1}{2}$ in. long. This secures a very powerful and direct motion.



103.

The Eureka machine, made by the Towanda Mower Company of Pennsylvania, Fig. 104, is a complete departure from ordinary principles, the great feature being direct draught. The knife, which may be 8ft. long, works in front of the wheels, being driven by spur gearing and a long pitman at right angles with a knife and bell-crank from the left-hand driving wheel. It is attached to the frame by jointed arms, so contrived that the angles of the fingers can be altered according to the nature of the crop. The pole is directly in the centre between the driving wheels, which are of large diameter, 42 in. The driver's seat is immediately behind the pole, with a spacious foot-board. The horses are yoked so wide apart, by means of a long neck-yoke, that whilst the near horse travels close to the standing grass on the space cleared by the track-board, the off horse walks in

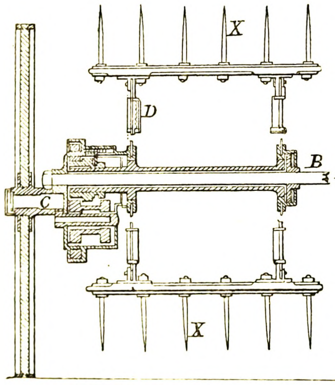
104.



the standing grass outside the knife. This is a point of importance; for if the knife followed the grass trodden down by the horses' feet, the cutting would be irregular, but as it meets the down-trodden grass on the return journey there is not any perceptible difference, and the Eureka machines work regularly, although the cutting is a quarter of an inch higher than the ordinary machines. One advantage of direct draught is that the machine can return along a parallel line, and therefore meets the down-trodden grass, and the operator can deal with a laid crop in the direction which secures the best result. For instance, it often happens that a heavy crop becomes laid in one particular direction; ordinary machines, cutting all round the field, must either go empty in one direction, or else follow the laid crop on one side, and inevitably make rough work. In such cases, by no means unfrequent, the Eureka is peculiarly suitable, because the whole crop can be cut at right angles to the direction in which it is laid. Another minor advantage is that it clears the ground straight before it, facilitating later operations.

Figs. 105 and 106 illustrate Jeffery's haymaker. This machine has a hood, which is fitted to cover a little more than one-fourth of the circle described by the tines of the forks, as they revolve when shaking the hay. As this hood is made of thin wood, zinc, or galvanized iron, the circulation of air which is produced by the rapidly revolving forks of the machine, is converted into a horizontal stream, whereby the hay is more effectually delivered. The galvanized wire netting hoods which have been placed at the back of the shafts did not have this effect. Also the delivery of the bulk of the hay was in a perpendicular direction, the result being that much of it fell on the shafts or horses' backs. This was a serious inconvenience and increased labour when the wind lay in the direction the machine was travelling. Fig. 106 illustrates the arrangement of the shaft-iron, and shaft for raising or lowering the tines D of the forks X as carried behind to work. The main axle B, Fig. 105, is supported at both ends by the frame carried on the axles of the travelling wheels. The ends of this carrying frame are called drum-heads. To these are fixed side-irons for attaching the shafts. Around the main axle a barrel revolves. This barrel carries the fork-arms, and it is by the way in which this drum is put in motion or stopped, that the efficiency of the shaking powers of the machine is acquired. In the first place a cog-wheel is fixed on the hub or nave C of the travelling wheel. As this revolves, it is made to work a pair of pinions cast together. These have a sliding motion on a fast-key or feather. The revolving drum is put in motion by the cog-wheel and pinion as the machine advances, and when it is required to put the machine out of gear, the sliding pinion is withdrawn and becomes idle. But as a backward as well as a forward motion is required in these machines, another double pinion is employed. This works on a bottom bolt. One of the cog-wheels of this pinion is always in gear with the driving cogs on the travelling wheel. Thus, when the double sliding pinion is withdrawn from the driving cog-wheel, and the large cog-wheel of the sliding pinion is geared with the other cog-wheel of the double pinion, the action of the forks is reversed. These pinions are shifted as required by a lever, for the reception of which at the same time a change is being made, there are three notches. According as the lever is in one notch, the machine is set for the forward or tedding motion; in the next it is out of gear altogether; and in the third notch it is set for the backward motion. This lever is jointed, and when it is left to itself it falls and the gearing remains locked till, shifting, it is again required. This self-locking is a perfect safeguard against injury by negligence or want of skill on the part of the driver. The use of spiral springs, one open and the other closed, for locking the forks, either when open for work or when closed for travelling or resting, is an arrangement by which the spring is always at rest, except at the moment the position is being altered, and the spring loses none of its power or elasticity.

105.



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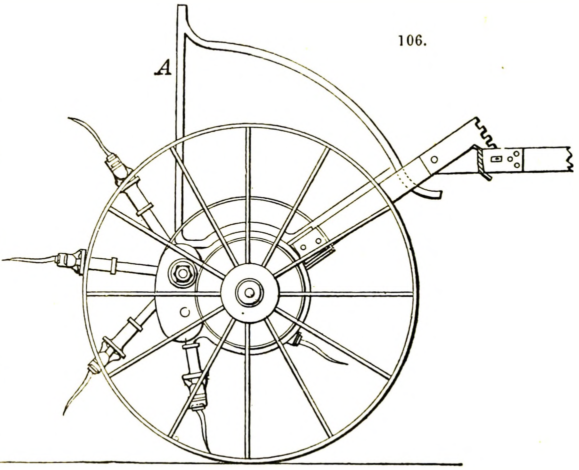
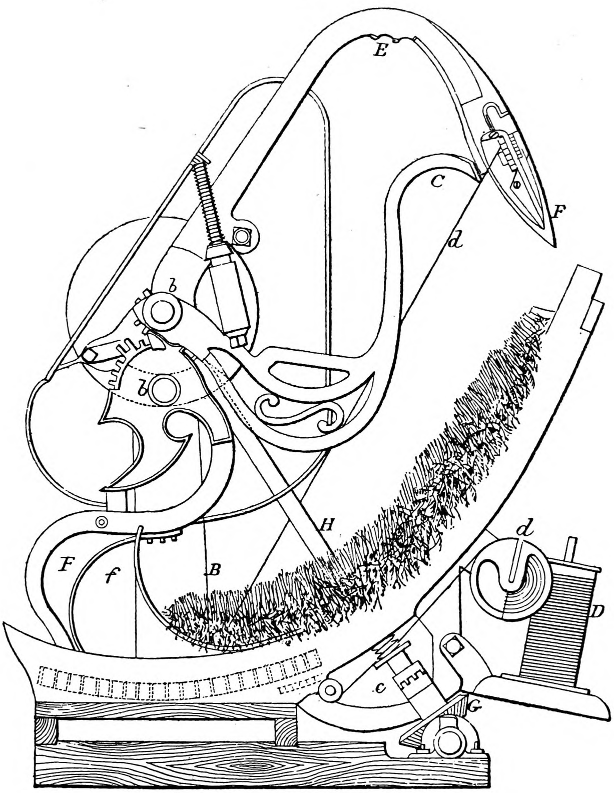


Figs. 107, 108, represent Wood's reaping and binding machine. To adapt the reaping machine to the binder, the rakes for throwing the corn off in loose sheaves are dispensed with, and the platform is made smaller and lighter. In the place of the large projection in the rear of the machine for the rakes to sweep over, a stage is placed behind the knives of sufficient depth for the corn to fall flat upon. Over this stage runs an endless webbing, that carries the corn to the side. It is then carried up an inclined plane, which rests on a frame over the driving wheel and gearing.

107.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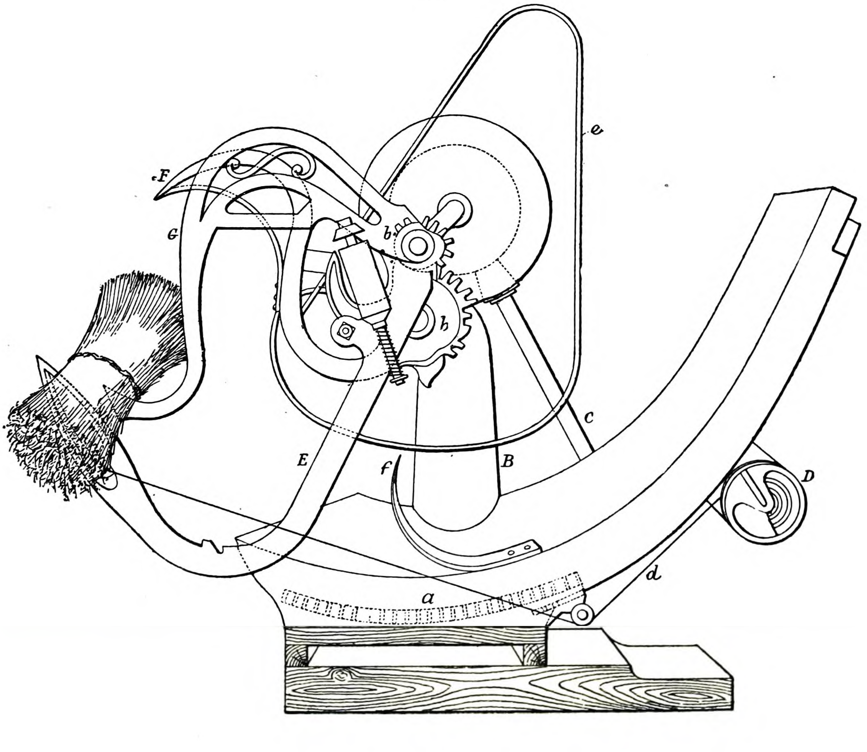
108.


e
F
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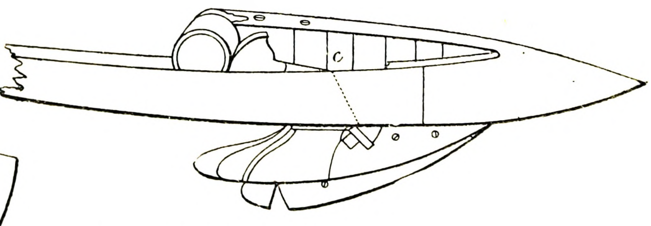
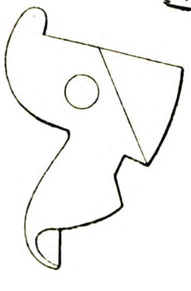
b
h
c
E
f
B
D
d
a

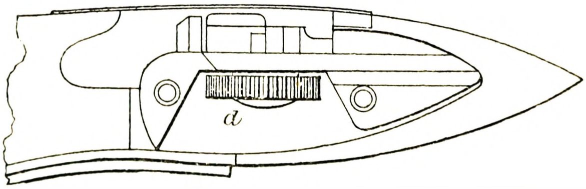
The binder is fastened on the outer side of the machine to the frame, which is carried over the driving wheel, the plane up which the webbing runs, and the side of the trough of the binder down which the corn falls, forming a figure something like the letter A with a slightly rounded top and elongated feet. *a*, Figs. 107 and 108 represents the left-hand sweep of this arrangement, the top being joined to the incline carrying the webbing on the machine. The gathering arms are shown in two positions, as coming down to gather a sheaf, and as rising to ride over again after the sheaf has been tied and delivered. The working parts of this apparatus are carried on an iron pedestal B and a forked arm, the pedestal being made fast to the bottom of the frame, the position of the arms being also shown at the section *b b*. These parts are driven by a shaft carrying wheels which run from the bottom of the frame as shown by *c*. The material used for binding the sheaves is annealed wire, and the reel for carrying which is shown at D, and the wire itself at *d*, the course of the latter being easily traced from the reel to the beak of the gathering arm. To get this wire round the sheaf and twisted subsequently, so as to hold it fast, is the work which this binder has to accomplish. The small reel *d* is a tension take-up reel, which is necessary, as the wire is longer when the gathering arm is going over, than it is when passing under the sheaf. A greater length of wire is then out than required to bind a sheaf. By this take-up reel, which contains a spring drawing 10 lbs. or 12 lbs., the wire is always kept in a requisite state of tension, which prevents the possibility of the wire kinking, or being in the way of the corn. The gathering arm travels at a uniform rate in the revolutions it makes. As it comes down to the trough, it enters as far as the elbow what may be termed a groove, which is formed by the trough being divided in the centre. Thus the beak, which has divided the falling corn the upper side of the trough, is carried completely under the forming sheaf, the pressure for tightening it being given by the small arm C carried within the larger gathering arm. But as this would give pressure on only one side, another arm F is brought into play. At the base of these arms there are half-circles cogged; by this means as the larger gathering arm enters the groove to gather a sheaf, the cogs at its base act on the cogs of the smaller arm, with the result that the arms meet each other at the bottom of the trough, and the sheaf is gripped at the time when the wire is being twisted and cut off. This done, the second arm retires until the gathering arm again enters the groove to gather another sheaf. The arm C, which is employed to assist in gripping the sheaf while it is being bound, is also utilized for pushing the sheaf beyond the point of the gathering arm, while it is in a horizontal position at the bottom of the trough. So soon as the sheaf is tied, this arm C begins to travel faster than the gathering arm, by which means the sheaf is pushed beyond the point of the beak of the gathering arm, when it falls to the ground. This third arm then rides over with the gathering arm till it reaches the sheaf. The arrangement of cogs admits of this arm riding over at the same speed as the larger gathering arm, then to cause it to start forward to produce a grip on the sheaf, and then to advance again to clear the gathering arm of the sheaf before it begins to rise. *e* is an iron rod to keep the grain from blowing in the trough. As it is fixed at one end only, it plays like a spring to let a bunch of corn, should a bunch occur, pass down in suitable form. The spring *f* is strong and yet flexible, so as to hold the sheaf while it is gathering and allow it to pass easily over them when it has been tied. Fig. 109 is an enlarged section of the beak of the gathering arm, in which the end of the wire is held. The difficulty presenting itself at first sight is the way in which the wire is held and carried on after it is cut. *a*, Fig. 110, is a small wheel lying horizontally, and *c*, Fig. 109, is a quadrant in the position of the groove. This the beak passes as it is carried through the groove, and the small wheel of the beak is turned several times. The wire is thus twisted. When this has been done, and the beak is just clearing the cogs of the quadrant, a small steel plate, Fig. 111, is brought into play. This acts as a combined cutter and gripper. As the beak is leaving the groove after the wire has been twisted at the bottom of the sheaf, the small knob or lug at the bottom of Fig. 111 is caught by a jog in the groove, and the wire is simultaneously cut and gripped, the grip being made between the cutter and the strip of steel *c* in the latter figure, as shown by a dotted line. The wire is held in the position just described after a sheaf has been tied, and the arm is starting to go over to gather another; as the arm goes

109.



111.





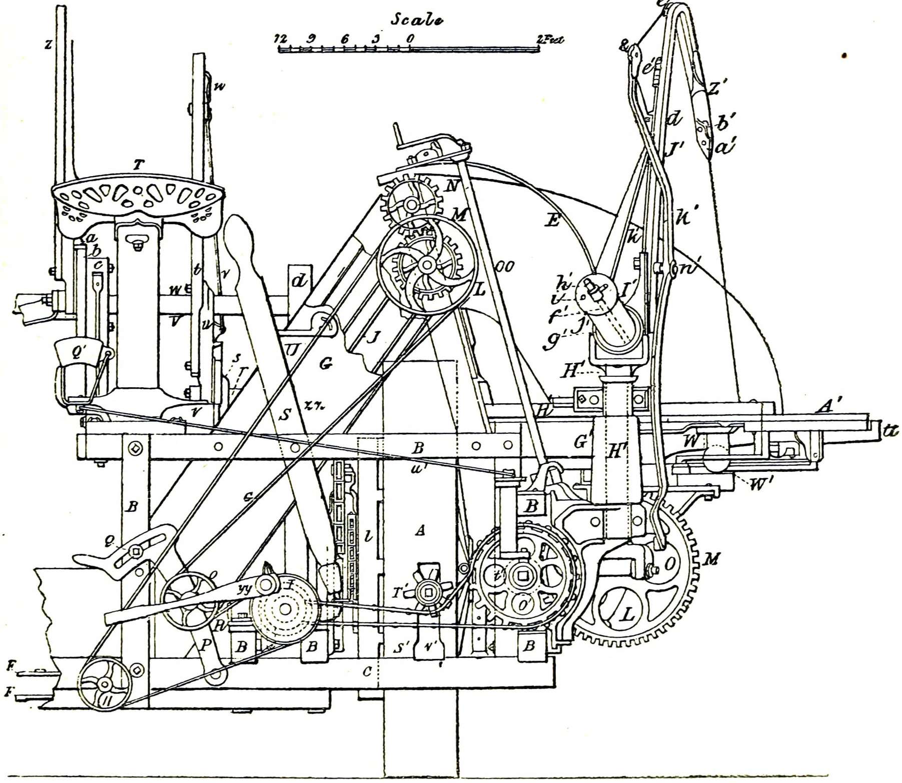
110.

over, the beak doubles the wire into itself, to so express it, for allowing which there is a slot just large enough to admit the wire at the base of the beak, and on one side of it. As the wire passes down this slot, it enters the cogs of the small wheel *a*, where it rests till the cogs of the quadrant are reached. At the moment this occurs, the lug at the top of Fig. 111 is caught by a jog, and the end of the wire is liberated for twisting as the small wheel turns in the groove. In this way is the double wire, the end liberated, and the part to be cut off, twisted tightly together as described. The process of gripping and cutting then follows. The cost of the wire is 1*s.* per acre, so that if the cost of labour for tying be 4*s.* to 5*s.* per acre, the amount of saving is clear.

Osborne's binder and harvester was invented in 1863, and it is stated to have been successfully used as early as 1866. Its operation is simple. The grain is reeled to the cutters with the ordinary reel. It is cut and dropped on an endless canvas apron, which elevates it over the wheel to the binding-table. The binder-arm with the needle, having the wire passed through it, passes the wire around the sheaf and carries it down to the twister, which is below the binding-table. There the two ends of the wire are taken in the twister, which performs its work as the sheaf is moved away from the next sheaf; thus while the sheaf is being removed from the table the wire is twisted and cut off, and the sheaf, securely bound, drops gently to the ground. The end of the wire is returned in the twister, and the operation is repeated at the will of the driver.

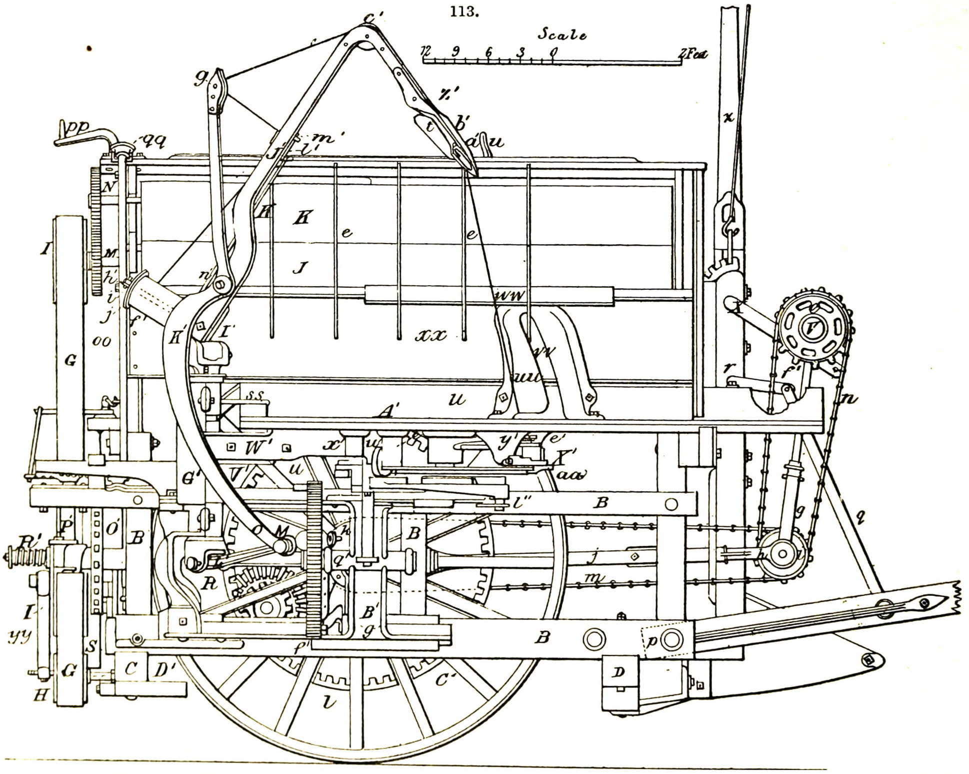
In the construction of the Osborne Harvester, Figs. 112 and 113, a framework B C D is provided for supporting the operative parts of the machine. This framework is supported on a main driving wheel A, on which the greater part of the framework is carried, the other end of the framework being supported by a wheel at the end, which is adjustable. The main wheel A is also adjustable by its axle being supported in slotted brackets, the radial centre of which is the pinion-shaft, with which the main gear-wheel *l* meshes. At the front edge of the framework and at one side of the driving wheel is the cutting apparatus, which consists of the ordinary slotted fingers and scalloped cutters, to which a reciprocating motion is given by a sway-bar, connected to the centre of the cutter-bar, and projecting rearward across the frame, to which it is pivoted near its centre, its rear projecting end being attached, by a connecting rod *y y*, to a crank I, which derives its motion from the driving wheel by a train of gearing connected with it, Fig. 112. A reel for gathering the crop is supported in front over the cutters, on the projecting arms of a rock-shaft X, which has a lever Z and holding devices, by which the driver can elevate or depress the reel at pleasure, and fasten and hold it in its adjusted position. This wheel is driven by a sprocket-wheel *e* on its shaft, connected by a chain *n* to a double sprocket-wheel *i* in a frame which is linked to reel-bearer *g* coincident with the centre of the reel-axis, and is also linked to the axis of the main wheel axle, so that the chain connecting a sprocket-wheel *k* on the hub of the main wheel with double sprocket-wheel, will impart motion to it, and through it to the chain connected with the

112.



sprocket-wheel on the reel-shaft, the axis of the links being the centre of the double sprocket-wheel; the relation of the chains and sprocket-wheels will not be changed in raising and lowering the reel. To carry the severed crop to its receiving platform A′ outside of the main wheel whilst the cutting apparatus is on the inside, an endless apron is provided, somewhat exceeding the length of the cutting apparatus behind which it is arranged, and supported on rollers at each end, the rollers being placed at right angles to the cutting apparatus, and supported in suitable bearings. The upper surface of the apron being slightly above the plane of the cutters, motion is imparted to it by a band attached to a pulley I on its shaft, the motion of the upper surface of the apron being from the outer end of the cutting apparatus towards the driving wheel. To elevate and carry the crop over the driving wheel A, two endless aprons K K are provided and arranged on the frame parallel to each other and inclining outwards over the driving wheel, sufficient space being left for the passage of the crop upwards between them. These aprons are supported on rollers, which have suitable bearings in an inclined framework G. The lower ends of these aprons are so placed as to receive the crop from the first apron named, and long enough to carry the crop over the driving wheel and deliver the same on the platform outside of the wheel, the platform being supported in nearly a horizontal position; a break-board attached to the framework under the elevator end of the apron serving to protect the wheel and prevent the accumulating sheaf from being drawn down by the lower apron. These elevating aprons have laths fastened across their surfaces the better to enable them to hold and carry up the grain. The continuous surfaces of the aprons have a motion upwards, which is imparted to them by the shafts M N of the upper roller

113.



being geared together; and one of the shafts M, having a band-wheel L around which a belt is passed, also around a band-wheel on the shaft H of one of the rollers of the apron behind the cutting apparatus, and also around a pulley on the crank-shaft I, gets its motion from a train of gearing connecting it with the main driving wheel. This train of gearing is the same that vibrates the cutters, and consists of the crank-shaft and its pinion, Fig. 113, a bevel wheel gearing with it, on the shaft of which is a pinion which gears with a gear-wheel *l* connected with the main wheel; this pinion *b* has a clutch-face *d‴* and interlocks a pin put through the end of the bevel-wheel shaft *c‴*, Fig. 112, and can by sliding the same on the shaft be made to lock with, or be disconnected from the same for stopping or starting the connecting gear or devices. For facility of doing this a shifting lever S is arranged in reach of the driver, and connected by intermediate devices to a fork *e‴* which embraces a groove in the hub of the pinion.

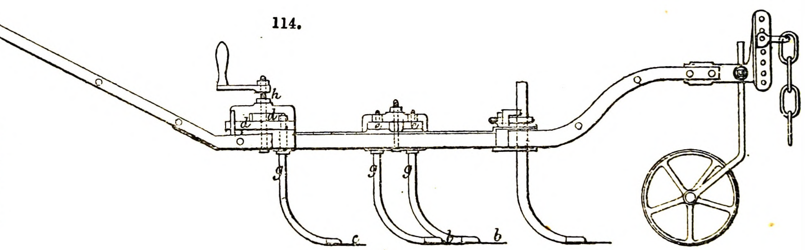
To bind the crop into bundles a framework having ways is provided, and is supported in guide-pieces D′ attached to the harvester frame B outside of the driving wheel. At one end of this frame, supported in bearings nearly in a vertical position, is a shaft H′, to which is attached an arm W′, which extends from it at right angles, and carries at its outer end a gripping, cutting, holding, and twisting mechanism for the wire of which the band is made. A double hook with bevelled edges is fastened to a shaft a short distance from its end, and on the end of the same shaft is fastened a similar double hook. The shaft is inserted in a metal frame or block; this block has fastened to its upper face a plate with its edges bevelled the reverse of the first hook, and close to which the first hook revolves, and with it makes a double shearing hook for cutting off the wire. A finger is pivoted to the block in the frame by one of its ends, its other end being bevelled off and of proper width to enter between the two hooks, and rests on the shaft against which it is pressed by a spring, so that in the reverse movement of the twister-shaft it will act as a clearer to remove any fibres or straws that may accumulate around it in twisting the wires. A pinion is fastened to the projecting end of the shaft on the opposite side of the frame or block from the twister. To the side of this block is fastened a piece of steel so as to form an open mortice. This block or frame is bolted to bracket on the end of the arm W′, with the shaft nearly vertical and the top of the upper hook far enough below the top of end of arm, which is in form of an open box, to give space for length of wire enough to form a twist. Above the twister is fastened a double plate with sufficient space between the plates for a gripping finger to move. These plates have a vertical V-shaped opening; a finger is pivoted to the plate and twister-frame, so that the projecting end of the finger will swing in between the plates and across the V-shaped opening, so as to clamp or grip the wire. This finger is operated by a connecting rod pivoted to it, and its other end to a short arm on the under side of the arm W′ that carries the twisting devices. In the open mortice at side of the twister-block is inserted a flat slot-bolt, so as to play free. The upper edge of the bolt, a short distance from its end, has a hook-shaped notch cut in it, and this, together with the mortice in which it is inserted, serves to grip and hold the end of the wire while the needle Z′ is conveying the wire round the bundle. The other end of this flat bolt is rounded, and has a spring for forcing it into the mortice and holding it there. To release it at the proper time the round end is connected to a short lever which has a friction-roller on it and is worked by a cam. A sector-rack X′ is pivoted to the under side of the twister-arm W′ so as to gear with the twister-pinion, and has a friction-roller pivoted to its under side, and projects into a cam-shaped groove in a frame which is fastened to the binder-frame, and below the twister-arm, and parallel to the plane in which it oscillates. This groove is of such form that in the oscillations of the twister-arm it will give a swinging movement to the sector-rack X′ sufficient for each hook to seize at the proper time its separate wire and separately sever and then twist them together for fastening them after surrounding the bundle. To an ear on this cam-frame is twisted a cam-piece, against which the roller on the lever that works the flat, holding both, strikes to open it and release the end of the wire, and sever the wire brought down by the needle-arm. Another pivoted cam is so arranged that the roller on the arm that works the connecting rod of the gripping finger will strike it to seize the two wires as they surround the bundle, grip and hold them firmly so that they may be severed and twisted together: they open and release the twisted ends of the wire for the discharge of the bundle, and hold it open until the time comes for again closing. To the top of the shaft from which the twister-arm W′ projects, is hinged an arm J′ carrying a pointed needle Z′ and a sliding shive to its side *m*′ connected with a spring *e*′, and to this sliding shive *l* are fastened the ends of a cord or band *n*′ long enough to pass round a grooved shive at the bottom *g*′, and of the wire-spool *j*′ which is placed on a spindle *f*′ inserted in the hinged end of the needle-arm I′. A connecting rod K is pivoted to this needle-arm and is extended downward, and attaches to a lever which is hinged to the lower end of the same shaft to which the needle-arm hinges. The other end of this lever is pivoted radially to a hub on a gear-wheel M′ which is overhung and has a shaft, the axial centre of which corresponds with the hinged point of the other end of the lever L′. The rotation of this wheel by means of the lever L′ hinged to the shaft of the twister-arm W′ gives to it an oscillating motion to and fro on that shaft, and at the same time the needle-arm J′ receives an up and down movement by means of the connecting rod K′ which unites the two. This connecting rod extends above its point of connection with the needle-arm and has on its end a shive. Motion is imparted to the wheel M′ to which the lever L′ is pivoted, by a feathered pinion on a grooved shaft N′, arranged parallel to the shaft of the gear-wheel, and driven by a sprocket-wheel and chain O′ connecting it with another sprocket-wheel on the crank-shaft inside of the crank-head I. On the shaft N′ to which the first sprocket-wheel is connected, is also a clutch P′ having teeth, which will lock with teeth on the sprocket-wheel, and this clutch is connected by levers and links to a treadle Q′, near the driver's seat T, so that he can disconnect the clutch from the sprocket-wheel at pleasure for stopping the binder, and by releasing his foot from the treadle, a spring R′ on the shaft forces the clutch towards and locks it with the sprocket-wheel, and its shaft revolves with it operating the binding mechanism. In threading the wire to the needle, it is passed first from the spool *j*′ around the sliding shive *l*′, then around the shive *g* on the top of the connecting rod K′ of the needle-arm, and then to the shive at the bend *c*′ of needle-arm, and down the needle, and between the shives near its point, and then to the holding jaw *y*′ below the twister.

With the wire arranged as stated, and the needle-arm J′ standing at the highest, and moving outwards from the delivery end of the elevator aprons K K, the harvesting and elevating mechanism previously put in motion, and sufficient material having been cut and elevated for a bundle, the driver releases his foot from the treadle Q′, and the binder is set in motion. The rotations of the wheel M′, to which the end of the lever L′ is pivoted, carries around with it the pivoted end of the lever; its hinged end being connected to the shaft H′ which supports the twister-arm W′, and its devices and the end of the wire that is in its holding jaw. The upper end of the wire, which is connected to the needle Z′ of the needle-arm J′, which is hinged to the same shaft, is also carried forward, pressing the wire against the accumulated sheaf. As the needle Z′ and twister-arm W′ advance towards the breast-board X X, below the delivery end of the elevating apron K K, the needle-arm J′ begins to descend, the point of the needle passing down back of the sheaf, and between the falling straws, separating them and surrounding the sheaf with the wire, the twister-hook rotating partially, so as to seize the strand of wire in the holding jaw; and after the other strand of the wire has been carried down below the twister, the gripping finger comes into action, and closes upon both wires between the twister and the bundle. The second hook of the twister is rotated so as to sever the second wire, and the first wire is released from the holding jaw, and it secures and holds the second wire, the first wire being severed by one of the cutting hooks, followed by the severing of the other wire by the other cutting hook, the ends of the wires being in the separate hooks as the arm moves outward, the rotating of the hooks, by the action of the sector-rack X, twists the ends of the wire together above the hook. When the twist is completed, the clamping finger is released, and as the arm starts on its return again, the finger is thrown entirely open and the bundle is free. This operation will now continue to be repeated once in 10 or 15 ft., according to the speed at which the binder is geared. When from the thinness of the crop an insufficient quantity has accumulated, by means of the treadle Q the driver disconnects the binder from the harvester devices, and starts it again when sufficient has accumulated, repeating the operation as frequently as the condition of the crop may require. He can also elevate and depress the reel at pleasure, as may be required by the condition of the crop, and can move the binder laterally by means of levers *p p* and shaft *o o*, so as to place the band at the proper point between the butt and head of the grain, and can also disconnect the operative parts of the whole machine from the driving wheel at pleasure.

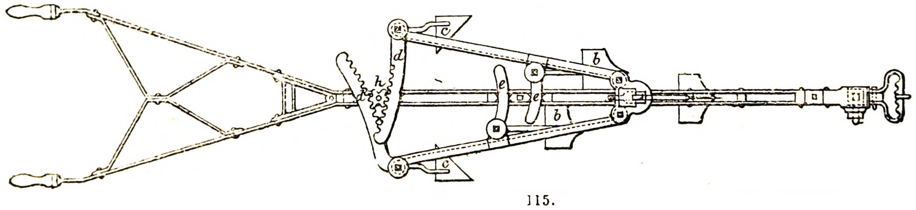
Horse Rakes and Hoes.—In ordinary expanding horse hoes the stems to which the shares are connected are formed of a circular section, and passed through circular holes in the arms, eye-bolts and nuts being employed to keep them in their places. The consequence of this arrangement is that when the hoe is at first expanded or contracted, the points of the shares do not stand parallel to each other, and it is necessary for the attendant to alter the position of the shares by slackening the nuts on the eye-bolts and turning the stems, and as there is no guide by which these can be set, they are sometimes placed in a position in which the shares are not left parallel to each other, when they are liable to turn, sometimes the case even when the stems or stalks and shares are set parallel to each other.

With F. C. Lake's horse hoes, Figs. 114 to 116, these disadvantages are avoided. In this implement the hoe-stems *g g* are caused to revolve in the sockets of the arms *f f* by means of the four segments or links *d d*, *e e*, which are so constructed that to whatever distance within the capacity of the hoe the arms are extended, the shares *b b*, *c c*, will point in a direction parallel to that in which the hoe is moving. The sides of the implement are caused to expand by means of two segments *d d* at the back part of the hoe, worked by the pinion *h*, which is so placed as to act with the segments in keeping the shares pointed to the front, and at the same time to extend or contract the arms according to the direction in which the pinion is turned.

114.



116.

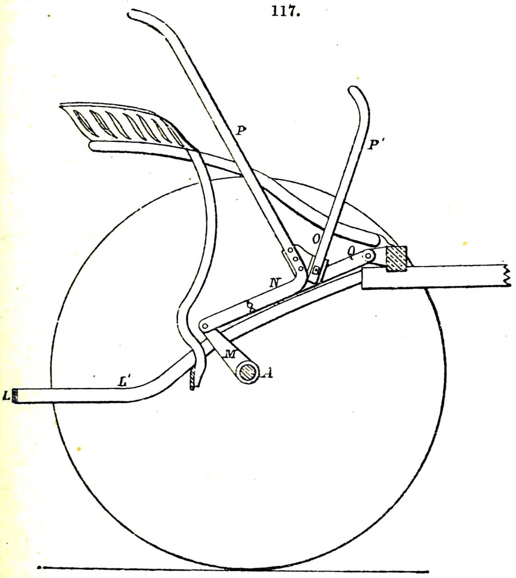


115.

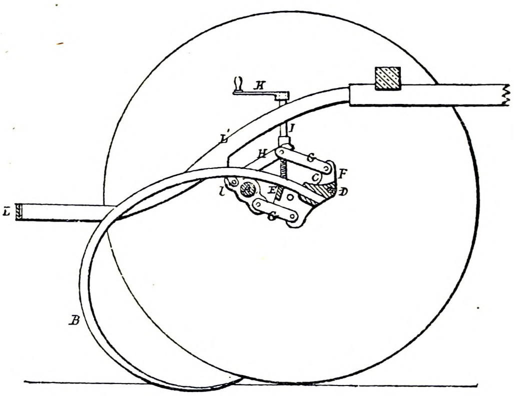
The ends of the stems above the arms, Fig. 116, are square in section, and upon them the segments *d d*, *e e*, are fitted and held in position by nuts which are slackened when expanding or contracting the hoe, thus enabling the stems to be brought parallel when turned by the segments. This imparts rigidity and steadiness of action to the implement.

Haughton and Thompson, of Carlisle, introduced in 1877 some improvements in horse rakes relating to the regulating of the height of the tines from the ground, and to means of fixing the tines in their sockets. The tine-heads are pivoted on a rod as usual, carried in two or more brackets or castings, each connected by a pair of parallel radius links with other brackets or castings fixed on the wheel-axle, the whole forming a parallel motion; and the improvements consist in the combination with each parallel motion of a diagonal regulating screw connecting the two brackets and acting on them so as to draw up or let down the tines in a vertical line when turned in the one or other direction; and in fixing the tines in their sockets by means of serrated notches at one side of the tines, taking into corresponding notches in one side of the socket, and secured by a wedge-shaped key driven in at the opposite side. Figs. 117 and 118 are vertical sections, and Fig. 119 a rear elevation, Figs. 120 to 122 vertical and horizontal sections, and an end view of the tine-head or socket. A is the wheel-axle; B are the tines; and C the tine-heads, pivoted on a rod D, supported on a frame E and two brackets Y, connected each by a pair of radius links G, with brackets H on the axle A. The brackets Y and H, and the connecting links G, form parallel motions for raising or lowering the points of the tines B in a perpendicular line. I is a regulating screw diagonal to the parallelogram formed by brackets Y, H, and links G. This screw turns in a bearing in an upward extension of the bracket H, with collars or shoulders to retain it in position, and its other end screws into a corresponding nut or female screw in the bracket Y; this screw is turned by a removable lever-handle or key K; L is the clearing frame supported on the axle A at its ends, which are slotted to allow of sliding on the axle and attached to the shafts by bars L, having each a downward extension by which it is connected by a pin-joint l with the adjacent brackets H; M is a crank-arm fixed on the axle A, and connected by a link N with a socket O, in which one of the two hand-levers P P^1, is fixed, according as the attendant walks behind or rides upon the machine; P^2 is a treadle to attach when working the tines from the seat. The link N and socket O are also connected by another link Q with the fixed part of the frame attached to the shafts. The attachment of the tines B to their heads C is shown in Fig. 120; the tine is serrated at one side b, and the corresponding inside surface c of the socket is similarly serrated, and the two are locked securely together by a wedge R at the opposite side driven in between the tine and socket.

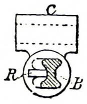
117.



118.



122.



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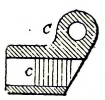
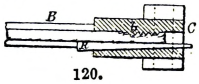
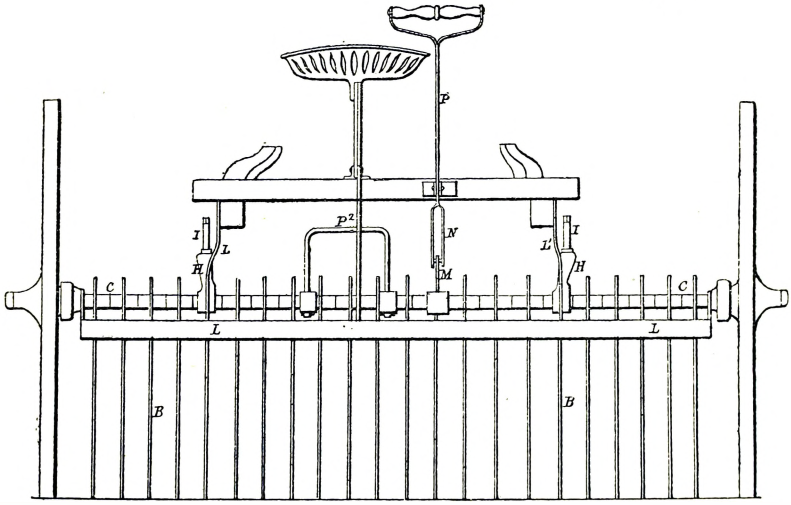




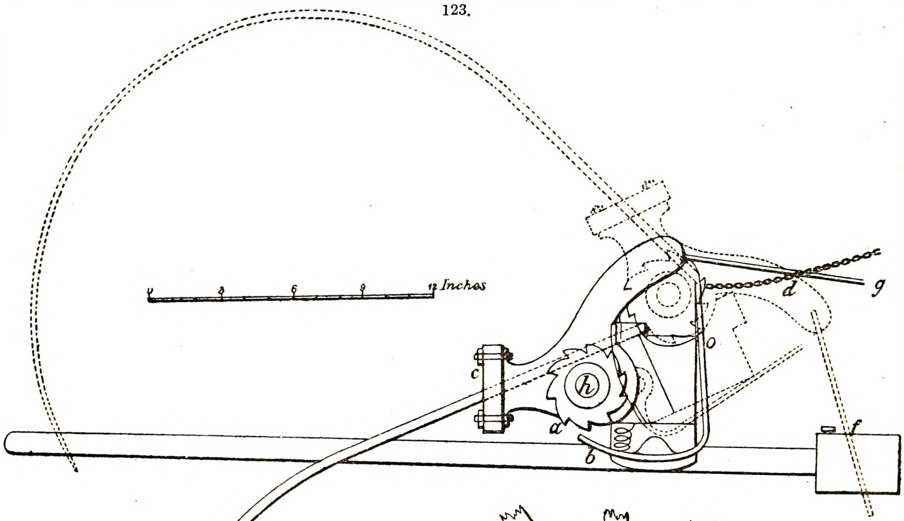
120.

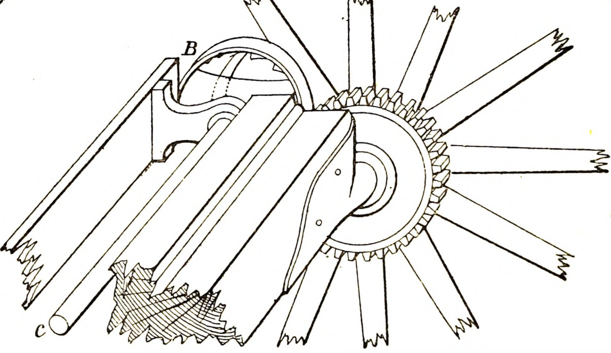
119.



Figs. 123 and 124 represent Rollins' American rake. This rake is self-acting, and both sides are alike. Of one side, A is the cogged boss, B the ratchet wheel, C the rod which runs through the centre ratchet wheel, D is the main axle. The point projecting from under the axle at b is a pawl, which is held on its pivot and, when resting, in its present position by a small spiral spring. A lever to this pawl is carried, it will be observed, in front of the main axle, to the top of which is attached a light chain *d*, the other end being fixed to the left-hand shaft. When the teeth are down and raking, the chain, lever, and pawl are in the position in which they are shown. While they are left in this position, and the rake is travelling, the two ratchet wheels revolve with the driving wheel. But when the driver finds the rake requires to be emptied, he depresses the chain *d*, which draws the lever forward, and raises the pawl into the ratchet wheel. This being so locked, the ratchet wheel is at the same moment prevented from revolving. The result is, as it

123.





124.

is cog-locked to the driving wheel, it is carried round, and with it the cross-bar, and the teeth are carried up by the cross-bar with the ratchet wheels. It is at this point that the main action in the principle of this machine is displayed. When the centre ratchet wheel is locked, and the end ratchet wheels are travelling up the driving wheels, the whole block between *e* and *c* turns bodily in carrying up the teeth of the rake. Thus, the lever *c* is brought down upon the head of the bolt *f*, as shown on the section of the cross-bar of the frame, and, as the lever strikes that bolt-head, it acts as a trigger, the ratchet wheel is liberated, and the teeth of the rake fall to their work by their own weight. If the rakings were exactly the same all over a field, or if it were no consequence to have them in a row for the convenience of gathering, this machine might be made perfectly self-acting.

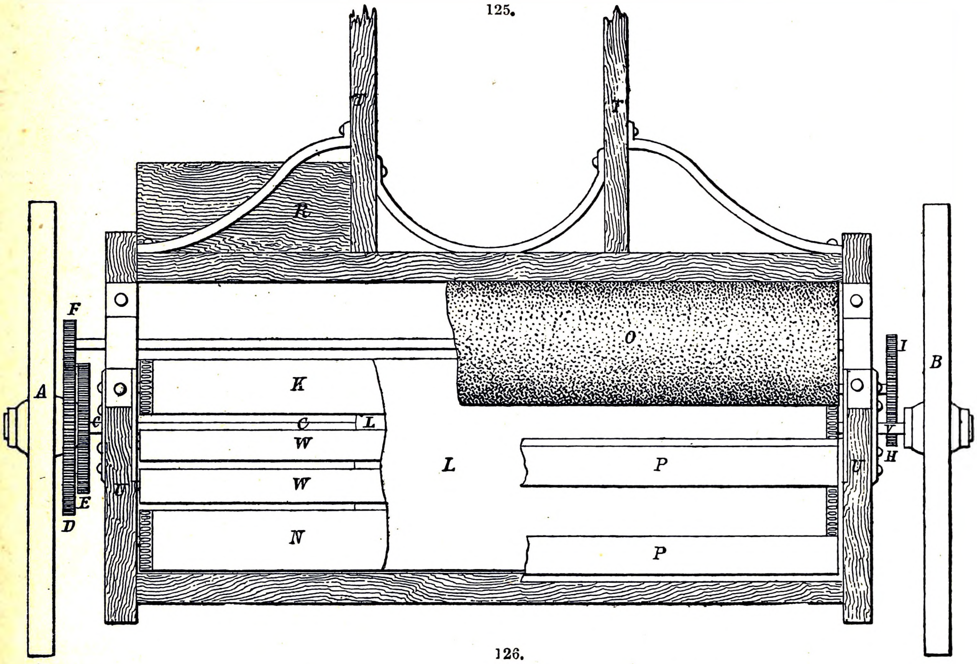
Figs. 125 and 126 are of a device due to Alexandre Gandrille, for spreading manure. In a cart an endless cloth bottom is arranged, working round supporting rollers together with a roller-brush working across and on the cloth bottom, the rollers supporting the bottom, the roller-brush being geared in connexion with the wheels of the cart, and as it is moved a uniform distribution of the contents takes place, owing to the movement of the endless cloth bottom which brings the material to the brush, and it is thus brushed out from the end of the cart.

The cart is made in the ordinary way but without any bottom, the bottom being formed of loose rollers, over and on which the cloth revolving bottom, intended to carry the manure, works; the brush is of hard fibre; the gearing of ordinary description, worked by the axle of the cart.

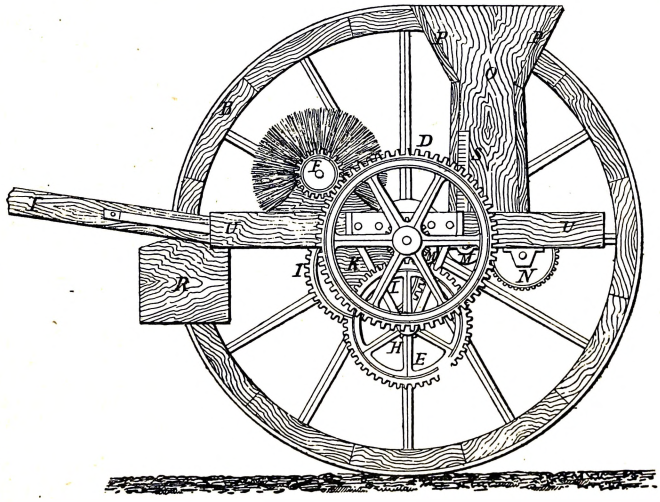
Referring to Fig. 125, A is the motion-wheel of the cart, to which are attached wheels **C D**; **B** is the opposite wheel of the cart; C, a cogged wheel actuating E below; D, cogged wheel driving F; E, cogged wheel communicating movement to the small axle G, on which is mounted wheel **H** placed below the axle of B; F, wheel communicating movement to the brush Q; G, axle of the wheels H and E; H, cogged wheel actuating I; I, wheel communicating motion to the roller K; K, roller, giving movement to the endless cloth L; L, endless cloth to carry off material placed in the box O; M, intermediate rollers supporting the endless cloth bottom L; N, fourth roller driven by the first roller K; O, box or receptacle for holding the manure or other material; P, ledges of the box O; Q, revolving brush; R is a box for the use of the driver; S, graduated scale for regulating the supply of material; T, shafts of the cart; U, frame of the cart; V, the axle.

It is evident that on the cart being set in motion, the wheels C D revolve simultaneously with the wheel A of the cart; C communicates motion to E, which is transmitted through G to A on the opposite side of the cart, where it is communicated to I, causing the roller K to revolve, which then through the motion of L carries on the movement to roller N, and similarly D moves F which causes the rotation of the brush Q.

125.



126.

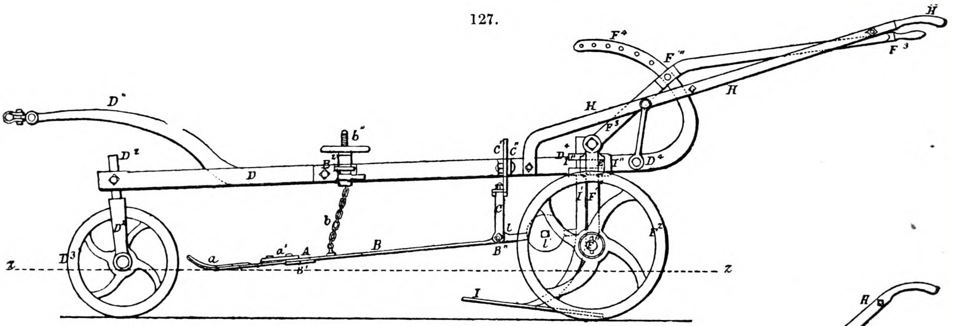


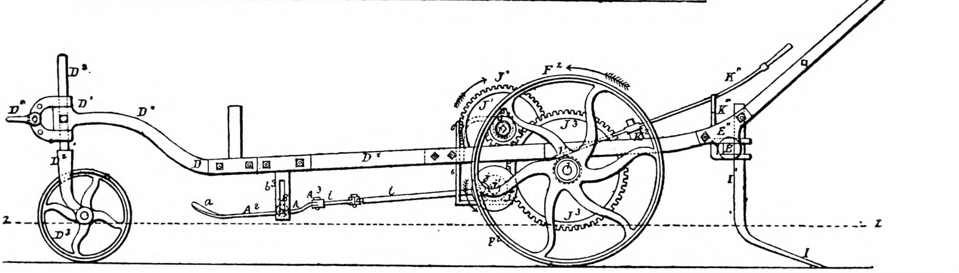
Figs. 127 and 128 have reference to an arrangement by Duncan Ross for cutting off the tops or leaves and the tails or roots of turnips, close above and below the body of the turnips respectively, while in the drills where they grow.

The novelty consists in having sharp-angled, preferably V or U shaped, blades or knives secured to the front end of an open horizontal frame, carried and oscillating at their back ends on arms, projecting down from a transverse bar secured to the main frame or beam of the machine with the knives directly above each drill at a height to suit the turnips, the limbs of the knives being open to the front and fitted with guiding horns, so that the shaws or tops of the turnips will be guided into and caught in the cleft of the knife, and so cut off during the forward traverse of the machine over the turnips, and in a plane parallel to the drills and surface of the field or nearly so, in contradistinction to the manner of cutting turnips hitherto by reciprocating and revolving knives acting and cutting laterally or transversely across the drills, or by simple angled knives.

In Fig. 127, the central beam D is carried forward, some distance in front of the topping cutters A, *a*, under the usual raised bow part D″ and shifting-pin drawing-shackle, where it has an eye D′ and screw or wedge for fixing the upper shifting end of the forked stem D^2 of the front carrying and guiding wheel D^3 to run in the central furrow between the two drills, indicated by the dotted lines *z - - - z*, and thus set the front end of the frame D at the proper height to suit the drills of turnips and the cutters. The back end of the beam D is secured to the centre of a strong cross-bar or frame-piece E, having strong eyes at its outer ends for carrying the oscillating shaft or axle F, which by arms secured at each end and projecting downwards with lateral studs at their lower end, carries the two back wheels F^2, which run in the centre of the two furrows close outside of the drills *z - - -z*. This back end of the frame can be raised and lowered on its wheels F^2 to suit the drills and tailing cutters I I′, by the oscillation of their carrying arms F′ and axle F, by a hand-lever. This raising and lowering lever is placed in the centre of the guiding shafts. In this arrangement of the topping cutters A, *a*, their oscillating frames B are made light enough to be raised by the inclined and forward action of the gathering-in curved horns *a* gliding over the top of the turnips in front of the cutters, and adjusted and hung at a proper height by short chains *b* near the front of the arms B, to give greater ease and flexibility in rising and falling, linked by hooking or swivel-arms above, to a hand regulating screw and wheel, secured in slots in the transverse carrying arms B^2 screwed or otherwise fixed to the beam D over the frames B, so that they can be quickly and easily adjusted to suit the height and width of the drills of turnips to be cut. The cutters A themselves are portable for removal and sharpening, secured by screws to the front end of the bars B. The ordinary root-cutters I are carried by strong stems I^1 projecting up and secured in eyes in the shifting and fixing blocks I″ secured by cotters to the bar E of the frame above. The front edge of each cutter I is set so as to project forward at the sides, and angled back at about 45° towards each other at the middle furrow, so as to cut off the roots or tails of the turnips by the forward motion of the machine, after the leaves have been cut off by the topping knives A in front, so as to deliver the turnips from the two drills into the one furrow.

127.





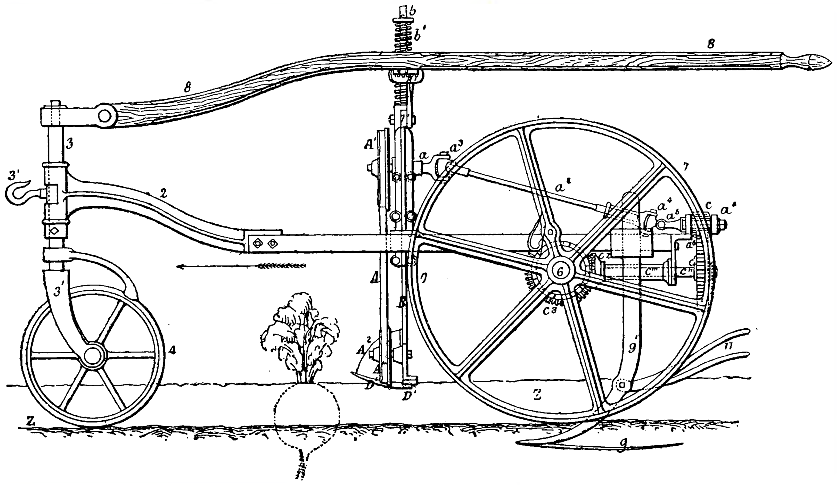
128.

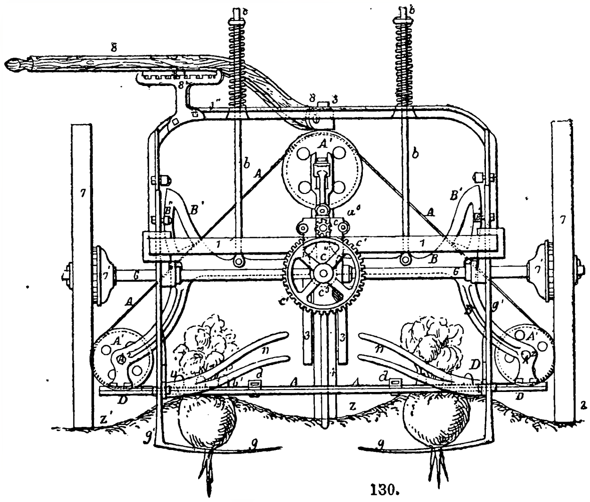
An ordinary turnip topping and tailing machine, as just described, consists of a main frame with two side and rear carrying wheels, loose on or coupled by clutches to their axle, running in the two furrows outside the two raised drills of turnips to be cut; there are cutter-socks attached by sockets and adjustable stems and holdfasts to the rear part of the frame for cutting off the tails or roots, and raising or throwing the turnips of both drills on to the surface of the central furrow ready for lifting, and a front bow or drawing beam with its fore guiding wheel running in the centre furrow with controlling gear and hand-lever or other equivalent mechanism for instantaneously raising and lowering the rear of the frame, with its cutters on the carrying axle and wheels, in relation to the surface of the ground.

Figs. 129 to 131 relate to an arrangement of turnip-topper due to John Brigham, of Berwick-on-Tweed. The open rectangular main frame 1 of the machine is of malleable iron secured in front at 1′ to the cast-iron central drawing beam 2, carrying the swivelling forked spindle 3 of the fore guiding wheel 4, running in the central furrow Z, and fitted with the hook 3′ in front for the coupling of the horse drawing tackle, the main back part of the frame being carried by the journal brackets of the main shaft 6 of the wheels 7, mounted loose on its extreme ends and running in the two outer furrows, and coupled to the shaft 6 by ratchet couplings and a spring pawl 7′.

The machine is guided by the hand-lever 8 secured on the top of the swivelling spindle 3 of the guide-wheel 4, and rests on the setting and retaining notched bracket 8′, at one corner of the vertical bow frame 1″, secured to and projecting up from the main frame 1, and which carries and guides the loose oscillating frame B, carrying the band-saw A and its driving and guide pulleys A′ A′, for cutting the tops off the turnips.

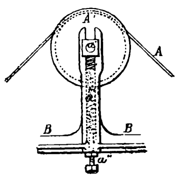
129.





130.

131.



The bar D is attached to the bottom of the vertical frame B, with two or more curved up-pointed finger-guards D′ secured to the bar D below, and projecting forward at some inches apart above the two drills of turnips so as to glide over them and embrace the turnip-tops between the fingers D^1, having the band-saw A working close above them. The frame B is carried by two adjusting links *b*, one at each side, passing up through the bow-carrying frame 1″, with the elastic springs above, so that the whole frame *b* and finger-bar D rises and falls over and across the two drills *z z*, according to the irregular size or height of the turnips as the fingers D′ glide over them. The frame B is guided and steadied vertically by the curved wings B^1 at its upper ends between the antifriction rollers B″ secured to the inner face of the vertical frame. The band-saw A is carried round the two small pulleys A″, revolving on studs A^2, secured to the lower ends of the frame B, quite beyond the fingers D^1 and above their carrying bar, so as to cut the tops as they enter these fingers.

The saw being steadied in guides *d* secured to the upper side of the bar D, inside the fingers D′, passes up from the outside of the two guide-pulleys over the saw-pulley A′, which is secured on the front overhanging end of the short spindle *a*, revolving in a tightening bush carried on a regulating spring with a pinching screw as shown in the back view, Fig. 131. The spindle *a* of the driving pulley A′ is turned by the angled shaft a^2, coupled to it above by the universal-joint coupling a^3, and below by a similar coupling a^4 to its pinion-shaft a^5 carried in the bracket a^6, projecting up from the back end of the frame.

The pinion *c* is driven by the spur-wheel c^1 gearing into it, and keyed on the overhanging end of the horizontal shaft c'' carried in the bracket c''', below the frame 1 and shafts a^5, a^2, and driven by the bevel-pinion c^2 gearing into the wheel c^3 keyed on the driving shaft 6, so as to drive the band-saw at a high speed from this shaft when it is coupled to its running traction-wheels 7 by the couplings $7'$. The roots of the turnips are cut by the cutters 9 formed on the lower forward end of the stems 9^1, secured by pinching screws and gripping blocks 10 to the rear sides of the frame 1, near the back end, and projecting towards each other so as to cut off the roots after the tops have been cut off, and with the assistance of the guards or gatherers 11 screwed to the lower part of the stems, deliver the dressed turnips into the centre furrow behind the machine ready for lifting and carting away.

Books upon Agricultural Implements;—Mangon (J.), 'Traité de Génie Rurale,' 1 vol., royal 8vo and atlas folio, Paris, 1875. 'The Journal of the Royal Agricultural Society of England,' 2nd series, London, 1868–78. Papers in the 'Engineer' and 'Engineering,' 1862–78. 'Proceedings of Institution of Mechanical Engineers,' 1872. 'Landwirthschaftliche Blätte,' Berlin, 1870–76.

AIR-COMPRESSORS.

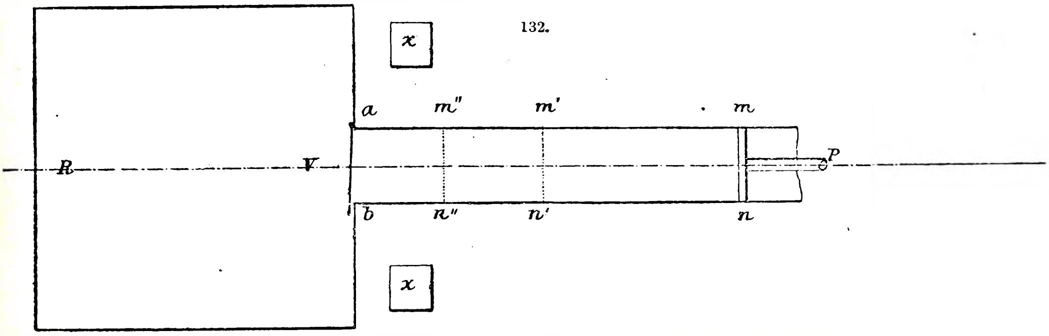
Certain disadvantages inherent in the nature of steam render it unsuitable for employment in some situations. When the pressure of steam is required to be applied at points remote from that at which it is feund convenient to generate or prepare it, a long line of intermediate pipes is needed for its conveyance. In the course of transmission, under these conditions, from the point of generation to that of application, steam loses much of its heat, and becomes in no inconsiderable degree condensed into water. A large proportion of the work stored up in the steam is in this way lost, and its use becomes in consequence uneconomical. In underground workings, the heat of steam constitutes a very serious obstacle to its employment. Rock-boring is commonly performed by machine drills; and if steam were applied to the driving of these drills, the temperature at the forebreast would, unless special and expensive means were provided to maintain a strong ventilative current, be rendered intolerable. The same consequences would ensue if steam were employed to actuate coal-cutters and hauling engines, or to propel mine locomotives, although the same degree of vitiation would not be reached. These disadvantageous qualities of steam have caused attention to be directed to compressed air; and of late this has been largely adopted in those circumstances which we have pointed out, and also in some others where its peculiar properties recommend its employment. Consisting as its does of permanent gases, condensation cannot take place; and as it may be obtained at atmospheric temperature, it is not liable to lose heat in transmission. But its great merit for underground use lies in the beneficial influence it exerts on the atmosphere of close places. Instead of heating the air, as steam would do, it has a powerfully cooling effect, in consequence of the expansion which it undergoes during its exhaustion from the machines. Moreover, as it consists of pure air, it contributes largely to the renewing of the atmosphere of the workings. Thus, compressed air is not only free from the defects of steam, but, while possessing all the practically valuable qualities of the latter, it offers, in addition, advantages of no small importance. These merits have led already to its adoption in numerous instances; and there is no doubt that its use will be very widely extended.

It should be borne in mind, when comparing steam with compressed air, that the latter is only a means of transmitting power; it is not, like the former, a source of power. Strictly speaking, no doubt, the ultimate source of power in a steam engine is in the chemical reactions, known as combustion, which take place in the furnace; but the force is developed, in the form required for use, by the transformation of the water into steam. In compressing air, no such transformation is effected; the force, derived from other sources, is merely stored up in it, in the same way that force is stored up in a spring put into tension. The force is usually obtained, either from steam itself, or from a fall of water; and the air is made use of as a medium, through which it is transmitted to the points where it is to be utilized.

Compressed air is air increased in density by the application of pressure. The density of the atmosphere is such as to give a pressure of about 15 lbs. to the square inch, that is, if, for example, a hollow cube be made air-tight, and then placed in a vacuum, the contained air will exert a pressure of 15 lbs. to the square inch on all the sides of the cube. If, instead of placing the cube in a vacuum, we force into it an additional quantity of air equal to that which it already contains, the same pressure of 15 lbs. to the square inch will be exerted upon its sides; because in the latter case we have doubled the density of the air contained within the cube. If now an opening be made into the cube, the excess of air, that is all that was forced into it, will escape into the atmosphere, as a portion of the contained air in the first case would escape into the vacuum; and it is evident that in thus escaping, this quantity of air may be made to do work. This is the principle upon which air is made to serve as a medium for transmitting power. The power which it is required to utilize is employed to force air into a vessel prepared to receive it; this densified air is then conveyed to the spot where the power is required, and the force absorbed in causing the increased density is reproduced by allowing the excess of air to escape into the atmosphere.

The compression of air is usually effected in a cylinder, by means of a piston moving within it. The cylinder is in communication, through a valve, with the receiver into which the air is to be forced. This valve is kept closed by the pressure of the air in the receiver, and will not open to allow a fresh quantity to pass until the piston has advanced far enough to increase the density of that in the cylinder, to equal the density of that in the receiver. Thus the delivery valve of an air-compressor is open during only a small portion of the stroke of the piston. If the air in the receiver have a pressure of two atmospheres, the valve will open when the piston has made half its stroke; if the pressure be four atmospheres, the valve will open when the piston has swept through three-fourths of its course. The compression of the air in the cylinder is accompanied with phenomena that have an important influence on the economy of transmitting power by this means.

Let *a m n b*, Fig. 132, be a cylinder, in which moves an air-tight piston P, and let the dimensions of the cylinder be such that when the piston is at the commencement, *m n*, of its stroke the contained air, at atmospheric pressure, may weigh 1 lb., also let this cylinder be in communication through a valve V with a receiver R, in which there is air having a density equal to four times that of the atmosphere. Under these conditions there will be a pressure on the valve V of 60 lbs. to the square inch. As the piston *p* moves forward, the air in the cylinder will be compressed. When the piston arrives at the position *m′ n′*, the air which occupied the space *a m n b* will be contained within the half of that space, namely, *a m′ n′ b*, and as its density has thus been doubled, it will exert a pressure of 30 lbs. to the inch upon the valve V. As the piston advances, the air is still further compressed, and its density will have again been doubled when the piston arrives at the position *m″ n″*. With this density, which is equal to that of the air in the receiver, the pressure on the valve is 60 lbs., so that the pressures on the opposite sides of the valve are equal, and the latter is consequently free to open. As the piston advances from *m″ n″* to *a b* the volume of air *a m″ n″ b* passes into the receiver. Thus it will be observed that during three-fourths of the stroke, namely, from *m n* to *m″ n″*, the force impelling the piston is expended in increasing the density of the air in the cylinder, and during one-fourth of the stroke, namely, from *m″ n″* to *a b*, the force is exerted in driving the air through the valve V into the receiver R.


132.

The foregoing would be the action of a perfect machine; but in practice other conditions occur to modify the results. During the compression of the air, the air does no work, and consequently the force expended is converted into heat. To propel the piston forward from *m n* to *m′ n′*, against the increasing pressure of the air, requires the expenditure of a certain quantity of work in the motor. As this work is done upon the air, it appears as heat, and the temperature of the air is consequently raised. The unit of heat being equal to 772 foot-pounds, the quantity of heat generated may be easily computed by dividing by that number the work done in compressing. For example, suppose the area of the piston to be 144 square inches, and the mean pressure for a stroke of 4 feet, 22·5 lbs. The work done in this case will be $22{\cdot}5 \times 4 \times 144 = 12960$ foot-pounds. Dividing this number by 772, we have $\frac{12960}{772} = 16{\cdot}8$ units of heat. As this heat is communicated to the air, we may readily ascertain what the temperature of the latter will be, at the end of this length of stroke. To consider this question more fully, let the piston be in the position *m′ n′*, and the density of the air, consequently, twice that of the atmosphere, and let the temperature of this compressed air be that of the surrounding atmosphere. Suppose now a body X, having the same temperature and being capable of imparting an indefinite quantity of heat, to be put in communication with the cylinder, Fig. 132, and the piston to be forced back by the compressed air to its first position *m n*. As the piston recedes, the volume of the air increases, and if no heat were communicated, the temperature would fall, for the air is now doing work upon the piston. But as the body X is in contact with the cylinder, which is here assumed to be a perfect conductor, the slightest depression of the temperature below *t*, causes heat to pass from X into the air, and thus its temperature is maintained constantly at *t*. During the retrocession of the piston, the air expands at constant temperature; and the question to be determined is; What quantity of heat has been abstracted from the reservoir X? for this is the quantity expended by the expansion of the air. The expansion curve in such case being a common hyperbola, it can be shown that this quantity of heat $= p\,v \log. r = c\,t \log. r$, p, v, c and r, being respectively the pressure, the volume, the difference between the specific heats of air at constant pressure and constant volume, and the ratio of expansion, the logarithm being hyperbolic. Thus, if H represent the quantity of heat expended, we have;—

$$H = 53{\cdot}15\, t \log. r.$$

Suppose now the body X to be removed, and another body X_1 of the same temperature and capable of receiving an indefinite quantity of heat, to be placed in contact with the cylinder, and the piston to be again forced into the position *m′ n′*. As the piston advances, the volume of the air is diminished; and if no heat were abstracted, the temperature would rise, for the piston is now doing work upon the air. But as the body X_1 is in contact with the cylinder, the slightest elevation of the temperature causes heat to pass from the air into X_1, and thus the temperature of the air is maintained constantly at *t*. During the advance of the piston, the air is compressed at constant temperature, and the quantity of heat transmitted into X_1 is equal to that abstracted from X; that is, it is equal to $c\,t \log. r$. Thus, if H_1 represent the quantity of heat expended during compression, we have;—

$$H_1 = H = 53{\cdot}15\, t \log. r.$$

The equality of H and H_1 is necessary, and it will be observed that the quantity of heat H emitted during compression, which quantity, as we have seen, is equal to H_1 the quantity absorbed during expansion, is the exact equivalent of the work done upon the air in the cylinder by the piston. The action of an engine working in this way, is to pump heat from the body X into the body X_1; and when this view of the action is taken, the equality of the quantities becomes obvious.

In the foregoing case, the air is compressed and expanded at constant temperature. But if the bodies X and X_1 are not applied, the temperature of the air will vary. We have now to consider the effect of this variation of temperature. Suppose again the piston, Fig. 132, to be in the position *m n*, and the temperature of the air within the cylinder to be 60° Fahr.; on the absolute scale, the zero of which is 461° below that of Fahrenheit, this would read $461 + 60 = 521°$. Let the piston be forced forward into the position *m″ n″*. As there is now no body X_1 to receive the heat due to the conversion of the work of the piston upon the air, the temperature of the latter will rise as the piston advances. The temperature at the end, or at any given intermediate point, of the stroke may be readily ascertained, by the aid of a table of common logarithms, from the following equation;—

$$\text{Log. } T_2 = \text{log. } T_1 + 0\cdot408 \text{ log. } R.$$

in which T_1 is the original temperature, T_2 the new temperature, R the ratio of expansion or compression, and 0·408 the ratio, minus 1, of the specific heats of air at constant pressure and constant volume. In the case under consideration, the original temperature T_1 is 521° and the ratio of compression is 4. Solving the preceding equation, we have;—

$$\begin{aligned} \text{log. } 521 &= 2\cdot7168377 \\ +\,0\cdot408 \text{ log. } 4 &= 0\cdot2456404 = (0\cdot6020600 \times \cdot408). \\ \hline \text{log. } T_2 &= 2\cdot9624781 \end{aligned}$$

The number corresponding to this logarithm is 917, and this is the temperature of the air on the absolute scale. On Fahrenheit's scale, the reading will be $917 - 461 = 456°$.

The important practical question now is; What influence will this heat have on the work of compression? We have already seen that when the piston is in the position *m″ n″*, the pressure upon it, due to the quadrupled density of the air, is 60 lbs. to the square inch. But when the volume of the air is constant, the pressure will vary directly as the temperature. In the present case, the temperature has been raised from 521° to 917°; that is, it has been increased in the ratio of $\frac{917}{521} = 1\cdot76$. The pressure upon the piston will, consequently, be $60 \times 1\cdot76 = 105\cdot6$ lbs. If this heat could be retained, no loss of power would result from its generation. As in the compression of the air, work has been converted into heat, so in the expansion of the air, heat would be reconverted into work. But in practice, the heat due to the work done upon the air by the compressing piston, instead of reappearing as work upon the piston driven by the air, escapes into the atmosphere through the sides of the receiver, the cylinder, and the conducting pipes. In order to see clearly how this loss occurs, suppose the delivery valve V to be closed, and the piston to be held in the position *m″ n″*. The pressure upon the piston is, as we have seen, 105·6 lbs. to the square inch. Of this pressure 60 lbs. is due to the increased density of the air, and $105\cdot6 - 60 = 45\cdot6$ lbs. is due to the increased temperature. As the temperature of the air falls, in consequence of the escape of the heat through the cylinder into the atmosphere, the pressure will diminish, and the diminution will continue until the temperature has fallen to 60° Fahr., which we have assumed to be that of the atmosphere, when it will be 60 lbs. to the inch. Thus the loss of work in this case, occasioned by the accumulation of heat, exceeds 43 per cent.

To avoid this great loss, air-compressing machines are constructed to compress the air at constant temperature. The body employed to take up the heat, the body X_1 in the case already considered, is water. In practice, however, the results are far from being so perfect as they were assumed to be in the theoretical case. It is impracticable so to apply the water as to take up the whole of the heat as fast as it is generated. The most effective arrangements yet adopted consist in surrounding the cylinders with cold water, and, at the same time, injecting water, in the form of very fine spray, into the air that is being compressed. In some machines, water is made to circulate through the piston as well as round the outside of the cylinder. It will thus be observed that the efficiency of an air-compressor largely depends upon the completeness of the means adopted for keeping the air at a constant temperature. It must, however, be borne in mind in adopting such means, that they complicate the machinery, and may themselves be a source of a loss of power.

We have now to consider the converse of the foregoing case, namely, the fall of temperature occasioned by expansion of the air. We have shown that when the piston arrives at *m″ n″*, the compressed air has a density of four atmospheres and a temperature of 917° absolute, or 456° Fahr. Let the piston remain in this position until, by the escape of the heat, the temperature has fallen to that of the surrounding atmosphere, namely, 521° absolute, or 60° Fahr.; and let the piston be then allowed to recede to *m n*. The question now is; What will be the temperature of the air when it has expanded to atmospheric density? The equation already given becomes, for this case;—

$$\text{Log. } T_2 = \text{Log. } T_1 - 0\cdot408 \text{ log. } R.$$

Here we have

$$\begin{aligned} \text{Log. } 521 &= 2\cdot7168377 \\ -\,0\cdot408 \text{ log. } 4 &= 0\cdot2456404 = (0\cdot60206 \times 0\cdot408). \\ \hline \text{Log. } T_2 &= 2\cdot4711973 \end{aligned}$$

The number corresponding to this logarithm is 296° absolute, or $296 - 461 = -165$ Fahr. It thus appears that the air which escapes from the exhaust parts of an engine driven by compressed air is excessively cold. A practical difficulty arising from this is the formation of ice in the exhaust passages. Unless means are provided for keeping the parts clear, they may be speedily blocked up, and serious delays as well as great inconvenience may result, when high degrees of compression are resorted to. The influence of this cold air on the atmosphere of underground workings is, however, very beneficial.

We have seen that, owing to the imperfection of the means employed for abstracting the heat, there must be a loss of power, due to the rise of temperature in compressing air. The amount of the loss will be greater as the cooling arrangements are less effective and complete. But there are other sources of loss, of inferior, but yet of very considerable importance. One of these is the clearance spaces at the ends of the cylinder. Suppose, for the sake of illustration, a cylinder in which compression is carried to six atmospheres. When the piston arrives at the end of its stroke, the clearance space contains air compressed into one-sixth of its volume at atmospheric pressure; and it is evident that when the piston commences its return stroke, this air must expand into six times its volume, that is, it must expand to its original volume, before the suction valve can open to admit a fresh quantity of air to be compressed. Thus there is lost at every stroke, a quantity of air equal to that contained in the clearance space. To remove altogether the necessity for a clearance space, columns of water have been employed in the place of a piston, in a manner to be hereafter described. These fulfil the purpose very satisfactorily; but it must be borne in mind that they are themselves a source of loss of work, by the inertia which they oppose to the motive force. Such compressors require to be driven at a low speed. They are commonly described as "low speed" or "wet" compressors, those in which a piston acts directly upon the air being designated as "high speed" or "dry" compressors. It should be observed that the contents of the clearance space includes the air in the receiver behind the valve, which air returns into the cylinder as the valve closes. This is called the "slip" of the valve, that is, the quantity of air which the valve, as it returns to its seat, allows to slip back into the cylinder. When the lift of the valve is high, this quantity may be considerable; and when the lift is very low, the resistance from friction due to the contracted passage may be great.

Leakage of the valves and pistons, and the friction of the moving parts, constitute sources of loss of greater or less importance, according to the degree of perfection attained in the construction of the machine, and the state in which it is maintained. As these sources of loss are greatly dependent for their existence upon design, workmanship, and supervision, they are capable of being reduced within narrow limits. It is, however, needful to remark here, that the loss of work due to the friction of the air in the valve-ways, and to the influence of the contracted vein, is by no means inconsiderable.

There is yet another source of loss of motive force, the influence of which is very great, and which increases with the degree of compression adopted. This source of loss, which has hitherto been strangely overlooked, exercises an important bearing upon the question of economy relatively to this mode of transmitting power, and is, therefore, deserving of careful attention. Since the air has to be compressed by the application of force, it is clear that the fraction of that force remaining, after the important deductions have been made for the losses already described, cannot be fully recovered, without working the air expansively down to the pressure of the atmosphere. As this is in all cases impracticable, there must always be a loss of work. In the case of machine rock-drills, which work without expansion, the loss is very great.

Compressed air is conveyed in pipes from the receiver into which it is forced, to the machines in position at the various points where operations are being carried on, throughout distances often considerable. In this transmission, a loss of work is occasioned by the friction of the air in the pipes. Numerous and exhaustive experiments have been made to determine accurately the value of the loss thus occasioned. From the results of these experiments, the following three conclusions have been deduced, namely; 1, that the resistance is directly as the length of the pipe; 2, that it is directly as the square of the velocity of flow; and 3, that it is inversely as the diameter of the pipe. Upon these conclusions, formulæ have been established, whereby the value of the loss of force may be ascertained with ease and accuracy. These formulæ show that, for pipes of the diameters usually employed for this purpose, and for distances not exceeding one mile, the loss of motive force, due to the friction of the air in the pipes, is of very small amount, when the velocity does not exceed four feet a second. As this source of loss is of little importance so long as the velocity is kept below this limit, it is unnecessary to discuss here the formulæ by means of which its value may be determined, or to illustrate the method of their application.

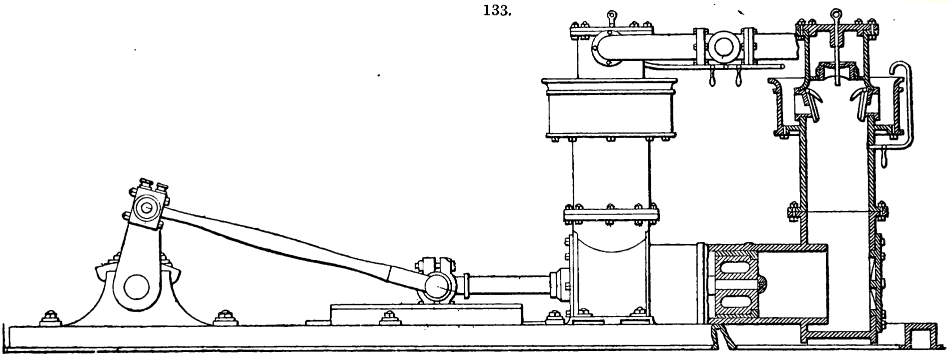
The steam pressure required in the boiler to obtain a given pressure in the air-receiver, may be readily ascertained by a simple calculation of the work done in compressing the air. It is evident that if there were no loss of power from friction and other causes, the work done in the steam-cylinders would necessarily be equal to the work done in the air-cylinders; therefore, when we have found the mean pressure in the air-cylinder, we have only to determine what boiler pressure is required to give, with a given grade of expansion, the same mean pressure in the steam-cylinder, when the pistons of both are equal in area and length of stroke. When the areas are different, of course an equivalent mean pressure must be found. But since there will be a loss due to friction, the mean steam pressure must be made somewhat greater than the mean air pressure, the amount of the excess being dependent upon the degree of perfection attained in the design and construction of the engine.

If the foregoing theoretical considerations have been fully understood, the respective merits and defects of the air-compressors now to be described will be at once clearly perceived.

The low-speed or wet compressors, have certain advantages over the high-speed or dry compressors, which should here be pointed out. By using the water column, the clearance spaces are almost wholly avoided, the pernicious influence of which spaces we have shown to be very great, when high degrees of compression are adopted. It has been ascertained that when these wet compressors are well constructed, and the density of the air is that of three atmospheres, they furnish about 96 per cent. of the volume of air, due to the space swept through by the piston. In dry compressors, such a return as this is never obtained. In the latter machines, there is always some loss from the escape of air past the piston and through the stuffing-boxes; in the former no such escape can occur. The water column also tends to keep down the temperature, by absorbing the heat generated, a practical advantage of some importance. Finally, there is less wear and tear in a wet compressor than in a dry one, and consequently repairs are less often needed. The most serious defect of the water column lies in the necessity for a low speed, the mass of water in motion being considerable. Hence, when large quantities of compressed air are required, recourse must be had to increased dimensions.

The wet compressor was first used by Sommeiller, at the Mont Cenis tunnel excavation, and the form which he adopted has not since been modified in any material degree. A compressor of this kind is shown in Fig. 133, from which the construction and the action will be readily perceived. It consists of a horizontal cast-iron cylinder in which the compressing piston moves; the piston is, in this case, packed with leather. The cylinder is firmly fixed upon a horizontal bed-plate. At each end of this principal cylinder, and in free communication with it, is another vertical cylinder or column, which, as well as the first, contains a body of water. Two gun-metal clack-valves, faced with leather, open from the outside inwards, and serve for the admission of the air; these are the inlet or suction valves. At the top of the vertical cylinders are the outlet or delivery valves. In this construction, we have upon each of the two faces of the piston moving horizontally a column of water of a certain height, which ascends and descends as the piston advances and recedes. During the descent of the column, the air is drawn into the space left free by the water; and during the ascent of the column, this air is compressed, and forced into the receiver. As the water is driven close up to the delivery valve, there is no clearance space. The quantity of water is so calculated that when the piston has arrived at the end of its stroke, the column reaches the delivery valve; a small quantity of water is, however, carried out through this valve by the air, and to replace this, a constant supply is brought in above the inlet valves, through a small pipe. This water enters the cylinder while the valve is open. This excess of water serves to keep the air cool; the requisite degree of opening of the cock upon the supply pipe, for a given piston velocity, is soon ascertained by experience. The compressed air enters a horizontal pipe connecting the two vertical cylinders of the compressor. The pipe connecting the compressors with the receiver, enters this horizontal pipe in the middle of its length. Beneath the point of junction of these two pipes is a well, to catch the water carried along by the compressed air. A small tube conducts the water back to the reservoir.

133.



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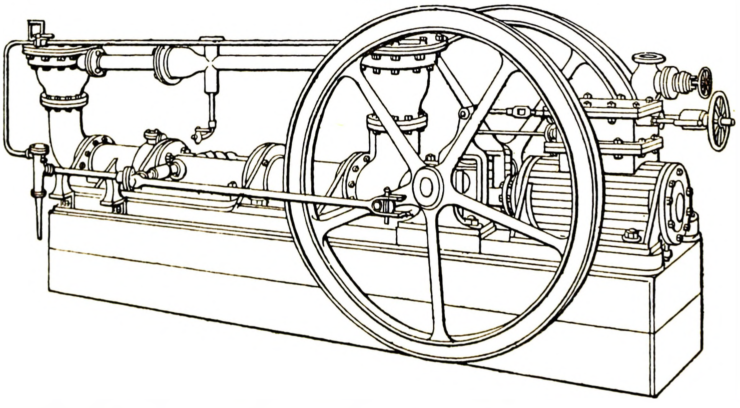
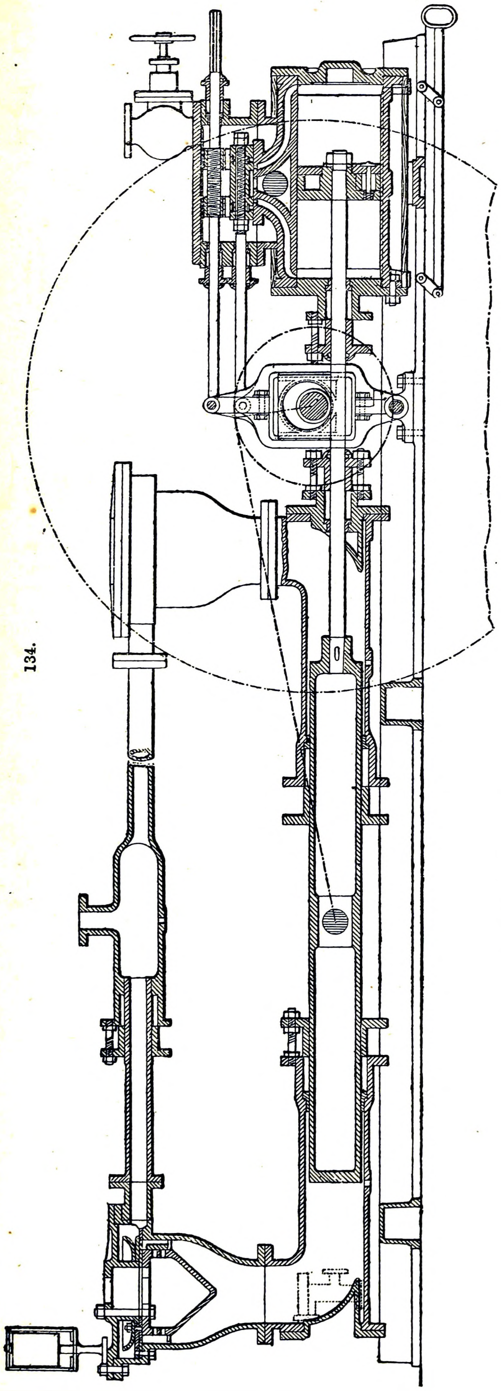


An improved form of this compressor, manufactured by the Humbolt Engine Works Company, at Kalk, on the Rhine, is shown in Figs. 134, 135. In this construction the piston is replaced by the plunger, the stuffing-boxes of which are readily accessible, and easily kept in order. The position of the valves will be seen in the drawing. Fig. 136 shows the newest pattern of this kind of compressor manufactured by this company. This is a very complete machine, and its action is said to be in the highest degree satisfactory. On the Continent, these wet compressors are generally used.



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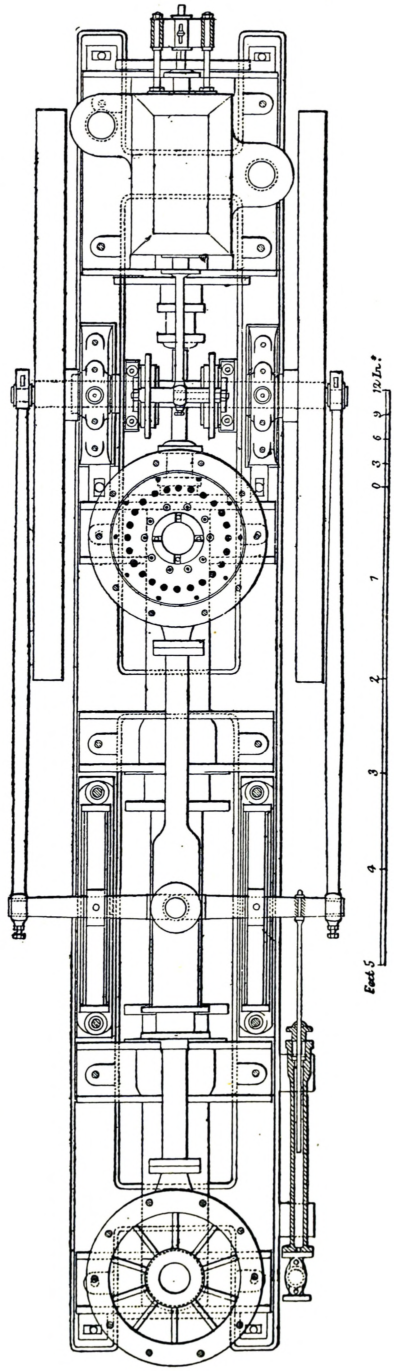
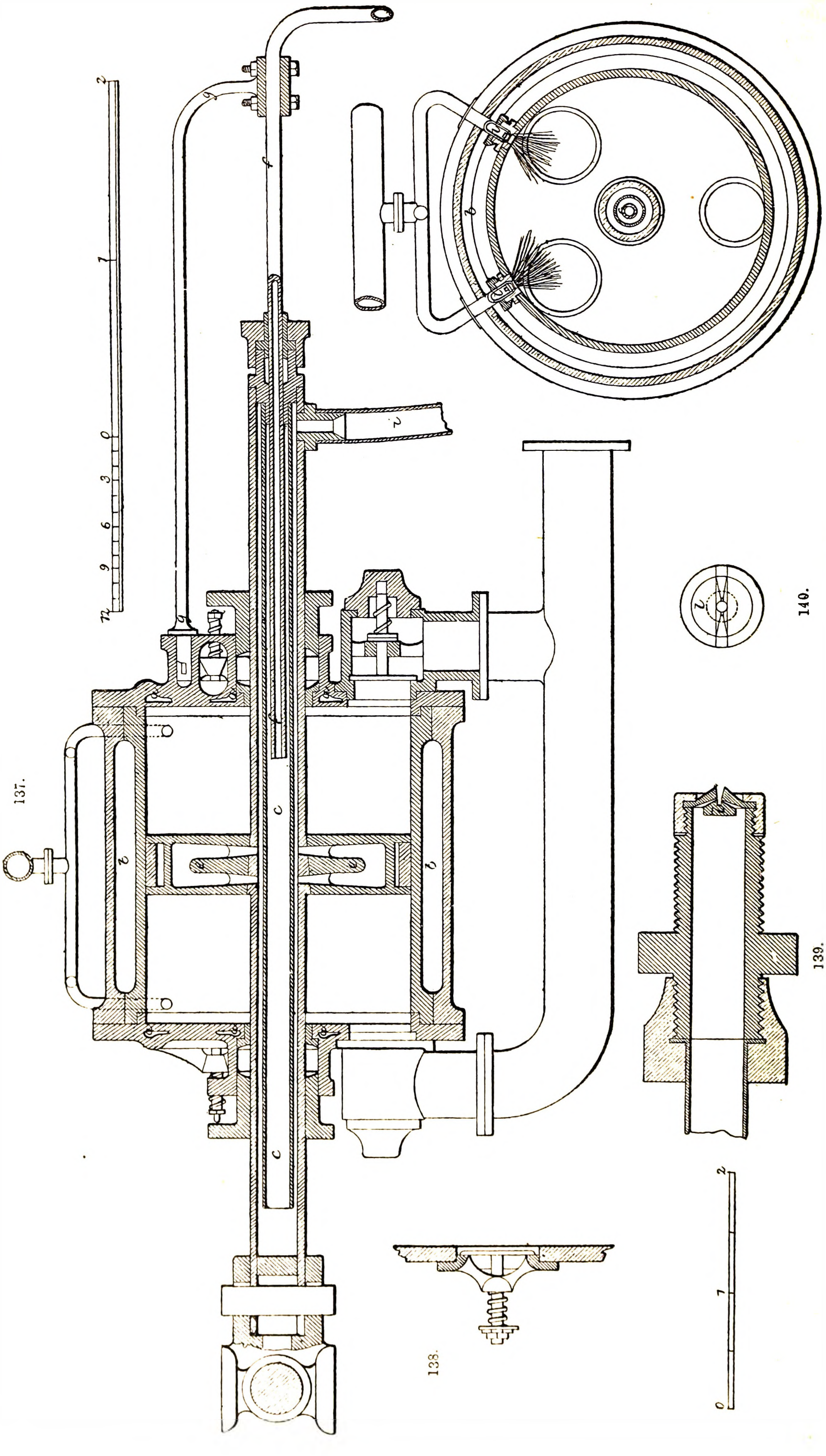


135.

Colladon's Air-compressor.—Colladon's air-compressor, the general arrangement of which is shown in Figs. 137 to 142, consists of a horizontal cylinder having a hollow piston, the rod of which, also hollow, passes through both ends of the cylinder, the suction and discharge valves being placed in the cylinder covers. The peculiarity in the construction of this compressor, which has been adopted at the St. Gothard tunnel, consists in the means adopted for cooling those parts of the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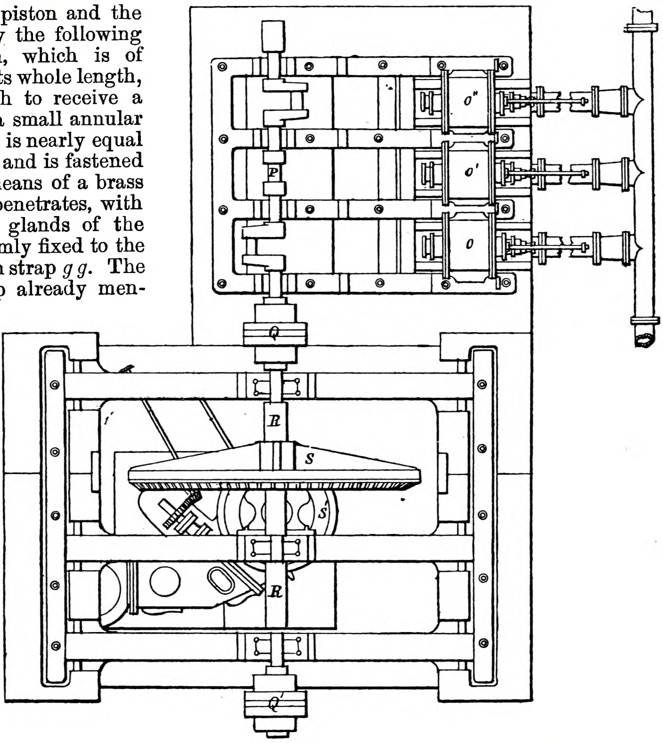
apparatus which are brought into contact with the compressed air. These means, which are very ingeniously arranged, are a circulation of water round the cylinder, and through the cylinder-covers, piston, and piston-rod; and an injection of water, in the form of spray, into the two ends of the cylinder. The circulation of the water in the cylinder-covers and round the cylinder, is effected by means of a small pump placed at the side of the cylinder, the plunger of which takes its motion from the cross-head of the compressor piston-rod. This pump forces the water through copper tubes having an internal diameter of about $\frac{3}{4}$ inch, into the spaces *a a*, Fig. 137, cast in the thickness of the cylinder covers, and into the annular space *b b*, formed between the cylinder and its outer casting or jacket; the water passes off through similar tubes situate in the bottom of the cylinder jacket. By this means, a constant and regular flow is maintained. The circulation of the water in the piston and the piston-rod, is carried on by the following arrangement;—The piston, which is of steel, is bored throughout its whole length, to a diameter large enough to receive a copper tube *c c*, and leave a small annular space around it. This tube is nearly equal in length to the piston-rod, and is fastened to it, at its back end, by means of a brass screwed plug, into which penetrates, with easy friction through the glands of the stuffing-box, a pipe *f f*, firmly fixed to the cylinder by means of an iron strap *g g*. The water, driven by the pump already mentioned, passes through this pipe into the tube *c c*. Having reached the forward end of this tube, it returns through the annular space left between it and the piston-rod, as far as the diaphragm *e*, which consists of a brass ring fastened to the piston-rod in the same line as the piston. This diaphragm obliges the water to pass into the piston, and to cool successively its two faces, as shown in the section, Fig. 137. The water afterwards escapes through the indiarubber pipe *i*, which is fixed to the back end of the piston-rod. The water is injected into each end of the cylinder by means of two small pipes, Figs. 137 and 141, fixed in the upper part of the cylinder, their ends being closed by a metal disc *l*, and pierced by two inclined holes opening opposite each other, and having a diameter of about one fiftieth of an inch. The water being forced under considerable pressure through these holes, by means of the feed-pump, one jet strikes against the other, and is thereby divided into very fine spray. The quantity of water to be introduced by this means, is so regulated by experiment, as to keep the air completely saturated. Under these conditions, even when the circulation in the interior of the piston is cut off, the temperature of the apparatus will not rise above 95° Fahr. All the parts, indeed, remain cool, with a velocity of sixty-five revolutions a minute, and with the air compressed to six atmospheres. In each of the cylinders there are two suction valves and one discharge valve, formed of very thin plates of steel with bronze seatings, the valves being kept in contact with the seatings by means of spiral springs coiled round the valve stem, Fig. 138. The dimensions of these valves are as follows; Suction valves, internal diameter of seating, $4\frac{1}{4}$ in.; external diameter of valve, 5 in. Discharge valves; internal diameter of seating, $3\frac{3}{8}$ in.; external diameter of valve, $4\frac{1}{3}$ in.

142.



At the Airolo end of the St. Gothard tunnel, twelve of these compressors have been erected, in groups of three, on one side of a common driving shaft, which is set in motion by four distinct turbines, by means of powerful bevelled gearing. The coupling boxes or clutches employed, allow the isolation of each of these four groups with its motor, while by another mechanical arrangement, which disconnects the bevelled gearing, either of the motors may be stopped, the corresponding group of compressors receiving motion from the common driving shaft. These arrangements greatly facilitate the carrying out of repairs, as they allow of any one group of compressors being stopped, without interfering with the working of any other part of the machinery; for even if it be necessary at the same time to repair one of the turbines and a compressor belonging to different groups, the remaining nine compressors can be driven, as already shown, by means of the common shaft in each group. The three compressors *o*, *o'*, *o''*, Fig. 142, are fixed side by side upon one bed-plate, and connected directly to a three-throw crank-shaft P. This shaft is connected by the couplings Q Q' to the driving shafts R R'. On the shafts are keyed the bevelled wheels *s*, driven by horizontal turbines.

The dimensions of the compressors at Airolo are:—

Diameter of piston	18·1	in.
Stroke of piston	17·7	„
The theoretical volume generated by the compressors at each stroke will be	2·63	cub. ft.
And at each end of the shaft	5·27	„
Which will give, for each group of three compressors, a volume of	15·81	„
At the normal velocity of sixty-five revolutions a minute this will give, for each group of three compressors, a theoretical volume of	1027·65	„
At a pressure of six atmospheres, which is the ordinary working pressure, this quantity will be reduced to	171·27	„
The actual volume, as proved by experience, will not amount to more than 70 per cent. of the theoretical volume, or	119·9	„

The experience gained at Airolo shows that Colladon's compressor, notwithstanding the complication of its parts, and the high velocity at which it is driven, does not require more repairs than the ordinary machines with water columns, which are driven at a much lower velocity; while the amount of its effective work will be fully equal to theirs. It is therefore superior to the latter, as, on account of its greater velocity, it is capable, with a smaller diameter and a shorter stroke, and a consequent proportionate reduction in the first cost, of furnishing the same proportion of air at a given pressure. It also possesses the advantage of being able, with a slightly increased velocity, to furnish volumes of air greatly in excess of the normal quantity. This advantage, which is altogether unattainable in a machine with water columns, on account of the great mass of water which has to be put in motion, belongs, however, to all those direct-acting compressors in which the velocity can be increased, in proportion as the cooling of the air is more completely carried out. The importance of this advantage can hardly be overrated.

With regard to the complication of its construction, this exists only in the means adopted for carrying on the circulation of the water in the interior of the piston and the rod; and although these means of cooling may be indispensable, in those cases in which we are precluded from adopting the more simple, direct efficient method of cooling by the water jets, as commonly used for compressing gas, it seems to be proved by the experience at Airolo, where the circulation of the water in the piston has not been maintaining the temperature within those limits which are favourable to the proper working of the apparatus, that if this circulation be abolished, the machine will become one of the most simple and advantageous air-compressors.

Sturgeon's Compressor.—The chief object sought by Sturgeon in the design and construction of his high-speed, air-compressing engine, has been to increase the percentage of the useful effect obtained from the force applied. This object he has endeavoured to attain, by the adoption of a new construction of inlet valves of his invention, which allows him to run his compressor at high speeds, without detriment to his machine, allowing for reasonable wear and tear.

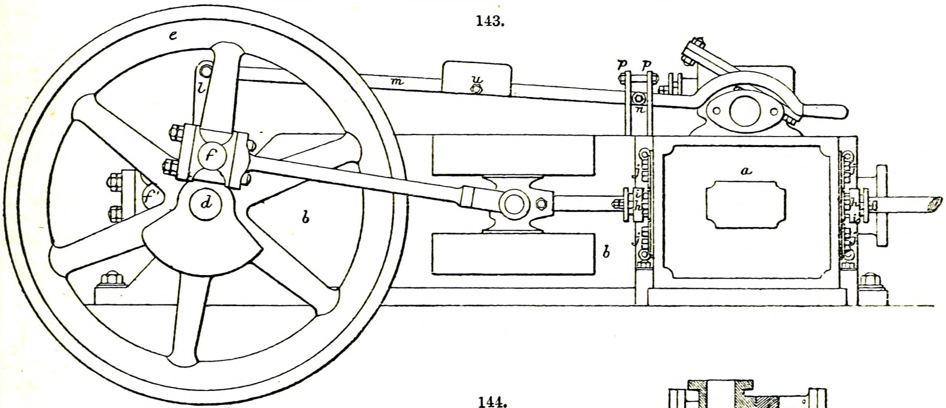
The receiver and steam-cylinder in this engine are cast in one piece, the air-compressor cylinder being bolted to the receiver, on the side opposite to that on which the steam-cylinder is placed, as shown in Figs. 143 to 145, in which *a* is the air-compression cylinder, *c* the steam-cylinder, and *b* the receiver. A fly-wheel shaft *d*, is carried by two pedestals, at the other end of the bed-plate or receiver *b*, and to this shaft are keyed the fly-wheels *e e'*, one at each end; the crank-pins *f f'* on these fly-wheels are fixed at right angles to each other, and are connected in the usual way to the two cylinder pistons. Now, as in the compression cylinder the pressure is smallest at the beginning of the stroke, and the greater portion of the work is done in the latter part of the stroke, whereas in the steam-cylinder the pressure is the greatest at the beginning of the stroke, and least at the end, the setting of the crank-pins at right angles to each other, enables the steam crank-pin to be in its best position to meet the increasing resistance in a similar ratio. It is said that by this arrangement, and with equal cylinder diameters on both sides, the air-compressor has registered, at one and the same time, double the steam pressure of the other cylinder.

To meet the varying requirements of the air-driven machinery in the supply of air, the following arrangement has been adopted, by means of which the steam engine is enabled to vary its speed automatically, so that when the air-driven machinery is stopped, the air-compressor may likewise stop.

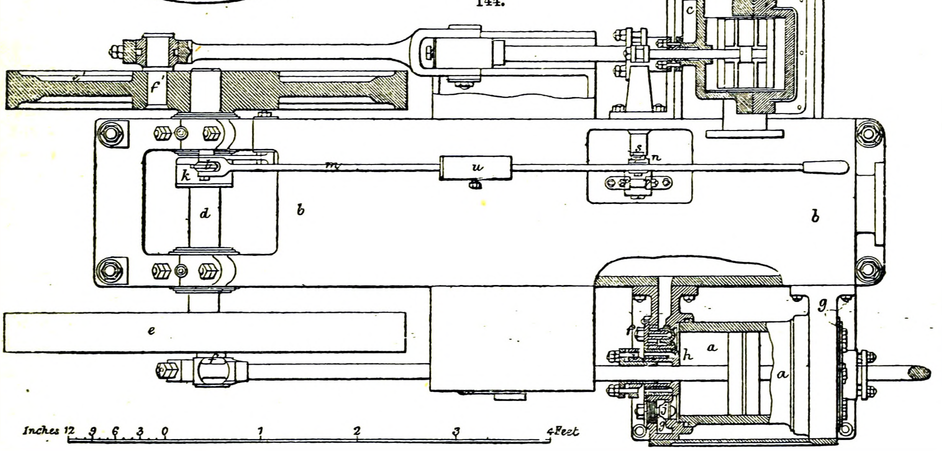
On the flywheel-shaft *d*, an eccentric *k* is placed, which works the valve of the steam-engine, in such a manner as to lengthen or shorten the travel of the slide, according as the pressure in the receiver falls below, or rises above, the required degree, which will necessarily correspond to an increase or a slackening of speed. A plunger fits air-tight in a recess made in the receiver *b*, and accordingly as the pressure increases or diminishes, so will the plunger rise or fall, carrying with it in the same direction the fulcrum of a lever *n*, whose centre is accordingly raised or lowered in the guides *p p*. Motion is produced in this lever *n* round its fulcrum, by its upper end being connected with the before-mentioned rod *m*. The valve-lever *s*, working from a fixed centre, has a projecting pin *r*, gearing into a corresponding groove cut along the length of the lever *n*, so that the reciprocating movement of the lever *u* is imparted to the valve-lever *s*. From this description it will be evident that the more the centre of the fulcrum of the lever *n* rises, the more will the travel of the valve be shortened; in other words, the less steam will be admitted into the steam cylinder, whereupon a slackening of speed must ensue. In order to regulate the pressure in the receiver *b*, a sliding weight *u* is attached to the rod *m*, which, according to the position in which it is set, can be made to maintain the degree of pressure desired in the receiver. When the centre of the lever *n* comes opposite the pin *r* of the lever *s*, the motion of the latter is stopped, and the engine automatically comes to a stand.

In order to reduce the heating of the compression cylinder, it is enveloped by a tank, which is kept constantly filled with cold water. As this water becomes heated, it is used as feed-water for the boiler, and thus a portion of the heat generated, which otherwise proves detrimental, is turned to some advantage. All the working parts of the machine are counterbalanced, and it is stated that, with a speed of 220 revolutions, or 440 feet a minute, no further foundation is required than a few wooden logs, placed underneath, to keep the fly-wheels from touching the floor.

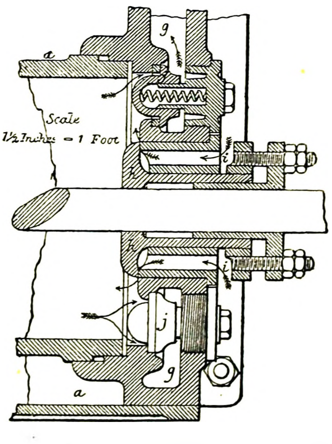
143.



144.



145.



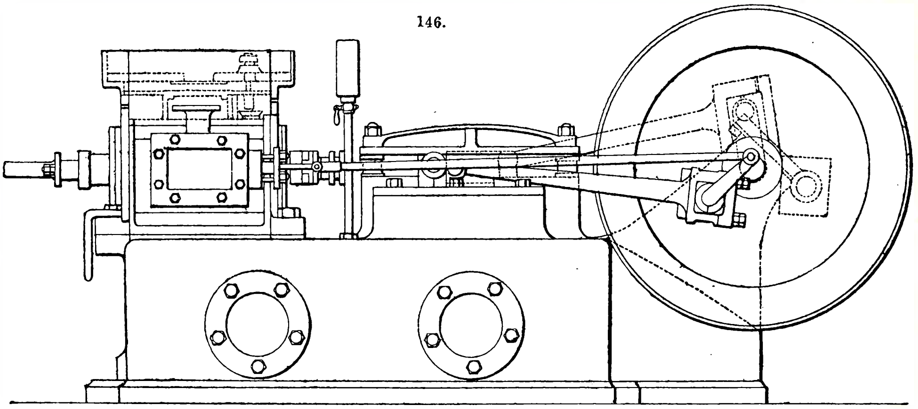
The construction of the air-cylinder valves, which form the chief innovation in this type of air-compressors, will be fully understood by a reference to the enlarged section, Fig. 145. These valves are fixed in the cylinder covers, and are duplicates at each end; the inlet valve *i i* is placed in the centre of the cylinder cover in the form of a circular ring. The cylinder piston is fitted at each end with stuffing-boxes *h h*, which are securely packed to the piston, so as to have a frictional hold thereon. The inner end of this stuffing-box *h*, is made to sit close on the inner surface of the cylinder cover, when the two come in contact with each other. Owing to the friction which this stuffing-box has upon the piston, as the latter recedes from one end of the cylinder, the corresponding stuffing-box becomes drawn in the same direction, until its travel is checked by the stop, shown in the figure, coming against the outside surface of the cylinder cover, when the piston completes the remainder of its stroke. The return of the piston brings the inlet valve close on to its inner seating, thus preventing the air from escaping out again whilst it is being compressed. To prevent these valves from coming in violent contact on their seatings, when working at high speed, the crank-pins are further so arranged, that at the moment of contact the crank-pin is almost on its centre, or at its lowest speed, and the valve is thus brought gently on to its facings, without violent concussion. The opening of the inlet valves is altogether independent of the vacuum formed in the air-cylinder, inasmuch as they owe their action to the driven piston. Moreover, the compressed air is here turned to account, in preventing the valve from opening, until the piston has travelled sufficiently far to allow time for the delivery valves to close.

The delivery valves *j j* are distributed over the whole inner surface of the cylinder covers, and are in direct communication with the receiver *b*, through the passage *g*; these valves are kept in close contact with their facings, partly by means of a spring thrusting inwards, and partly by means of the back pressure exerted on them by the compressed air in the receiver *b*. As soon as the pressure in the air-cylinder, acting on the inner surface, becomes greater than the counter-pressure, the springs become compressed, or, in other words, the compressed air in the cylinder forces its way through the valve openings and the clear passage *g*, into the receiver *b*, to be there stored. The back pressure on these delivery valves causes them to close again, and the inlet valves are then ready to open inwards. It will be seen that for the purposes of repairing or cleaning, these delivery valves can be removed, without detaching any fast joints.

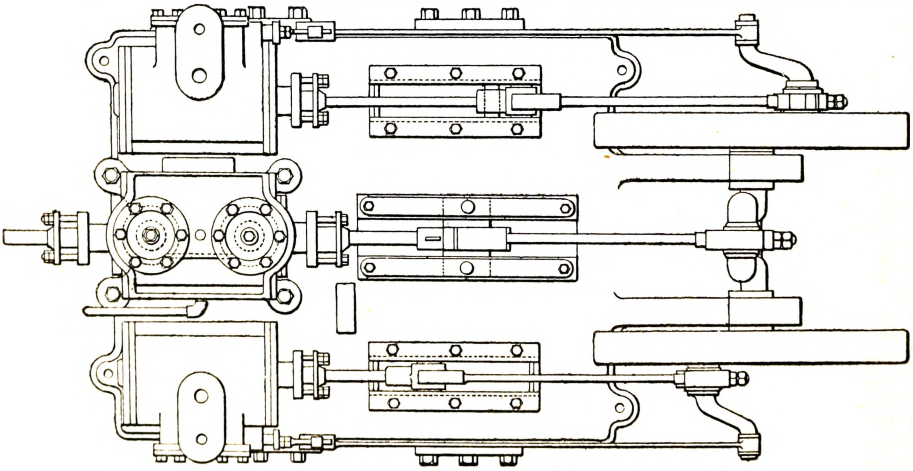
Hathorn's "Reliance" Air-compressor.—In this machine, which is made by Hathorn and Co., of London, the improvements lie chiefly in the design and construction of the valves, by which clear air-ways are obtained, and prompt and certain action is secured. A reference to Figs. 146 and 147 will show that the designers have aimed at and attained simplicity and compactness, qualities of very great importance.

It will be seen that the air-cylinder, which is in this case 9¼ in. in diameter, is placed between two steam-cylinders, 6½ in. in diameter. They all have the same stroke, 10 in.; one crank shaft serving for the three. The middle of this shaft is cranked for working the connecting rod of the air-piston, having discs or fly-wheels keyed on at both ends. The discs are fitted with crank-pins, on which work the connecting rods of steam-pistons. Forming continuations of the crank-pins are eccentric throws for actuating the slide valves, so as to avoid the wearing surface of eccentric sheaves actuating in their straps. The connecting rods are of the marine type, with simple and efficient provision for taking up gear. The foundation plate forms the air-receiver; it is stayed with internal feathers cast in, which render it capable of bearing any pressure up to 200 lbs. on the square inch. The hand holes on both sides are for convenience in casting; a pressure gauge and relief valve are also added.

146.

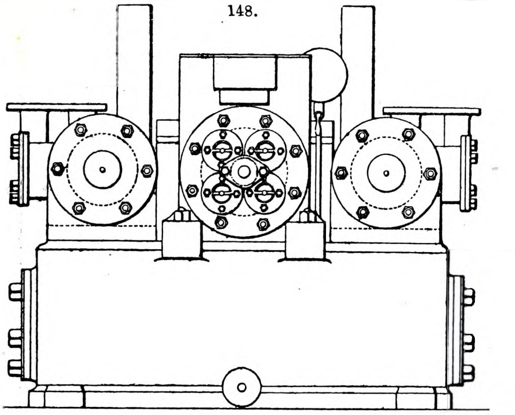


147.

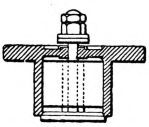


Besides the simplicity and compactness of the main parts, the valves, both for inlet and delivery, deserve attention. The old three-winged valve, with mushroom top, frequently sticks for one-third of its stroke; besides, its great weight adds considerably to the mechanical power required to drive the machine. Again, the cylindrical valve, working on a central guide, with a thimble for keeping it air-tight, soon wears unevenly and causes the thimble to break. The inlet valve, shown in section and plan in Figs. 149, 150, is a cylindrical valve, guided by a central spindle, $\frac{1}{2}$ in. in diameter, and working in a hollow cylinder. The seat is formed by a conical edge turned on the overlapping flange; while a passage is afforded for the air by a portion of the periphery, about an eighth of an inch wide, being turned out, as will be seen by the drawings. The travel, which depends on the size of the cylinder, is regulated and limited by screwing up the nuts on the guiding spindle. For a $9\frac{1}{4}$-in. air-cylinder, the valve is $1\frac{3}{4}$ in. in diameter, there being four arranged in each cylinder cover, as shown at Fig. 148; and for a $12\frac{1}{2}$-in. cylinder six valves of the same size are provided. The valves and their seating are quite flush with the inside of the cylinder cover, being recessed therein, so that the piston can come home within $\frac{1}{16}$ in., whereby dead space is avoided. Any single valve can readily be taken out, if it should become clogged, without breaking the joint of the cylinder covers; or one valve could be screwed up so as not to work, and the compressor run with the other three, without increasing their travel. The valve fits easily in its casings, and as it is counterbalanced by the air, the friction is reduced to a minimum. When the piston begins its stroke, the inlet valves open by atmospheric pressure and air enters the cylinder. The return stroke compresses the air and forces it through the two outlet valves, which are screwed on to the top of the cylinder, as will be seen in Fig. 146. One of these outlet or delivery valves, with its case, is shown separately in vertical section and plan in Figs. 151, 152. It has, as will be seen, a central guide, and is slightly coned on its outer edge to form the seat. A set-screw in the cover adjusts the travel; and a slight spiral spring, introduced between the spindle and the end of its guide, serves to deaden the shock on opening, and also to close it smartly.

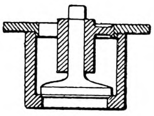
148.

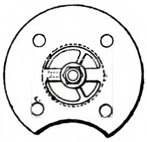


149.

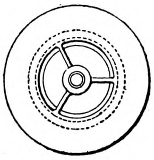


151.



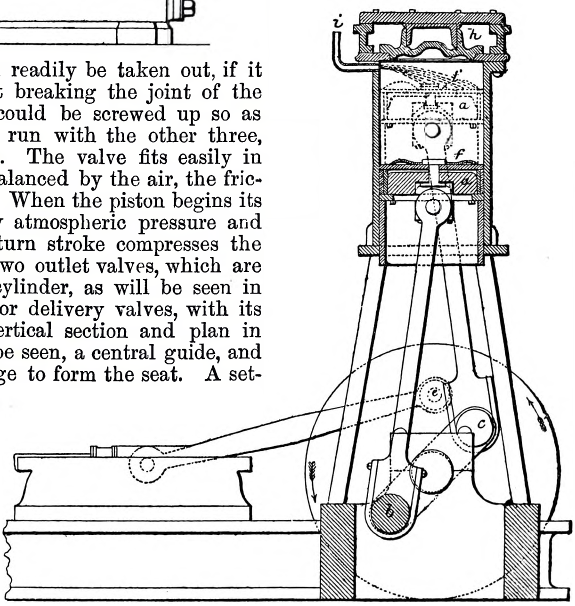


150.



152.

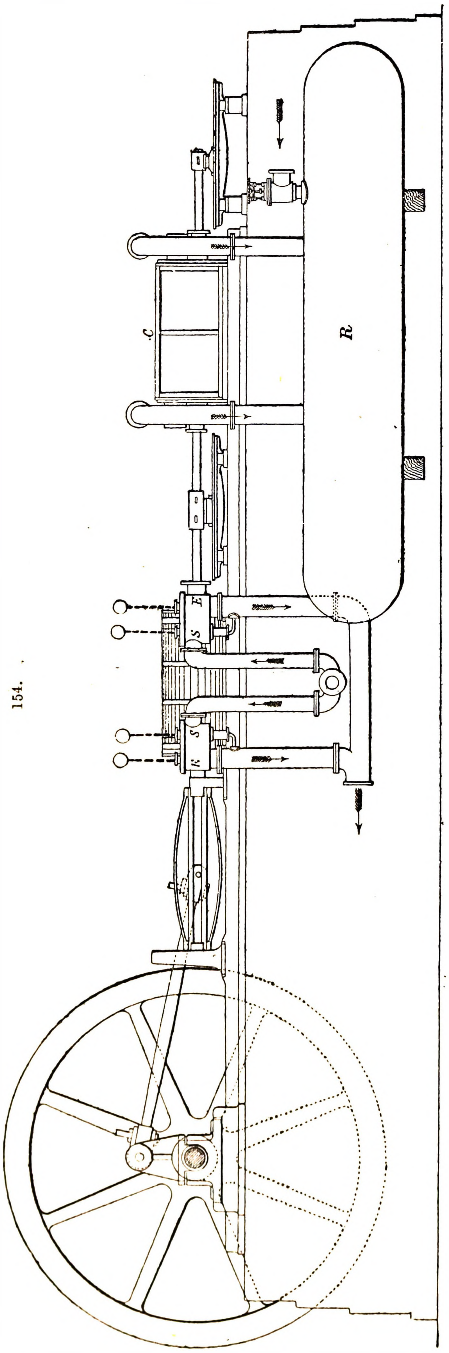
153.



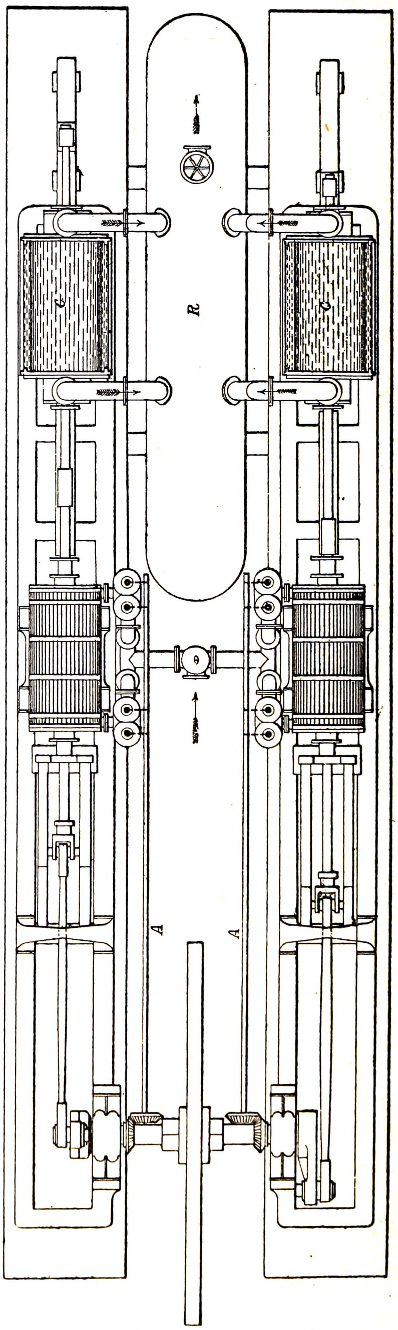
The cylinder is surrounded with a water-jacket, through which cold water constantly circulates, to take up the heat generated by the work of compression. The air-passage is cast on the top of the cylinder and on one side of it, forming a connection with the reservoir as short and direct as possible. There is no complication in the fixing of the cylinder on the air-reservoir. Both surfaces are merely planed true; and round the orifice of the air-passage a channel is cut in the bed-plate, into which a piece of lead wire, $\frac{1}{8}$ in. in diameter, is inserted to form the joint. The arrangement of cranks, the angles of all three being equally divided, is such that, when each of the steam-cranks is at the most effective part of its stroke, the air-piston is exerting its highest effort in delivering the greatest force of air.

The Burleigh Compressor.—The Burleigh air-compressor is remarkable for the simplicity of its construction; it has been in use now for a number of years, and at some very important works of excavation, the chief of which is the Hoosac tunnel in America, where it is stated to have given entire satisfaction. An elevation of this compressor is shown partly in section in Fig. 153. It consists of two vertical air-cylinders, the pistons of which are driven by a horizontal engine. It will be seen in the section of the air-cylinder that the pistons *a* are worked from a shaft, the cranks *b* and *c* of which are set at an angle of 180 degrees. The driving crank *e* makes with these an angle of 45 degrees, so that the greatest work of the motor piston corresponds with the greatest resistance opposed to the compressing piston. The valves *f* and *g* are circular plates, held in place by vertical guides. The compressed air from the two cylinders is forced into a common chamber *h*, and conducted thence, through pipes, to a receiver; to take up the heat generated by the work of compression, a jet of water is thrown into the cylinder through the pipe *i*. This water serves also as a lubricator. At the bottom of the receiver is a cock, which is opened at intervals to discharge the water carried over into it.

Fowler's Air-compressors.—A pair of air-compressors constructed by John Fowler and Co. is shown in elevation and in plan in Figs. 154 and 155. These engines are coupled together at



154.

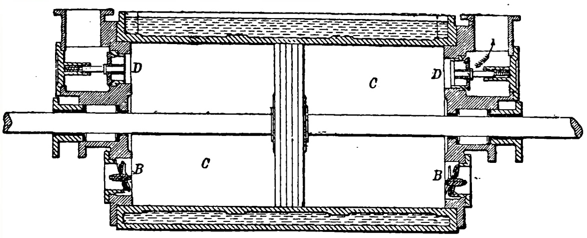


155.

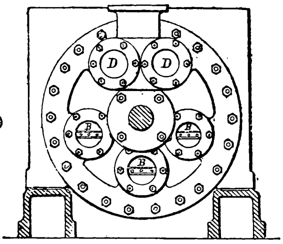
right angles, and have 34-in. steam and 40-in. air-cylinders, the stroke being 6 ft. Steam is used at a pressure of 70 lbs. to the square inch, and is cut off at one-fourth stroke; the air is compressed to 40 lbs. to the square inch above theatmosphere. The steam and exhaust valves are of the ordinary Cornish equilibrium type, and are 8 in. and 9 in. in diameter respectively. The steam-valves are worked by a cam on a horizontal shaft, which is driven by mitre gearing from the fly-wheel shaft; the exhaust valves are worked by an eccentric on the same shaft, and are set to close at one-sixteenth of the stroke from the end.

The inlet and the outlet valves of the air-compressing cylinders C C are shown in Fig. 156, which is a longitudinal section through the air-cylinder and covers, and Fig. 157 is an end view of one cover. The inlet valves B B are of cast iron with leather flaps; there are three of these in each cover. The two outlet valves D D, also in the cylinder-cover, are of brass, and have mitre faces, $1\frac{1}{4}$ in. long, inclined at an angle of 30° to the valve-spindle. Valves made of vulcanized indiarubber, and brass valves with common short mitres and flat faces were tried; but none were found to answer so well as those shown in the figures.

156.

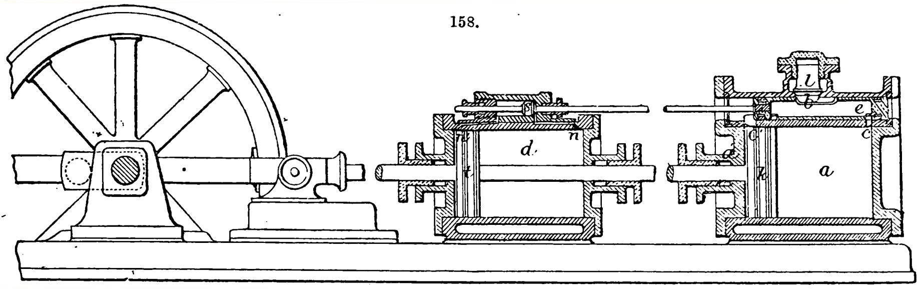


157.



These engines are intended to work at twenty revolutions a minute, or at a piston speed of 240 ft. a minute, and to indicate 482 horse-power. The regulator valve is set to admit sufficient steam for driving them at this speed, against an air-pressure of 40 lbs. to the square inch, and they are then self-governing; for should the machines not take air from the receiver as fast as it is forced in by the engines, the pressure in the receiver, and consequently the resistance to be overcome, increases, and the speed is diminished. If the engines come to a stand, and remain standing for such a length of time that the steam left in the cylinders has not force enough to put them in motion again, they are started by admitting steam through a small pipe, leading from the main steam-pipe to each cylinder-cover. The air-cylinders have water-jackets open at the top, as shown in Fig. 156; the air is forced into the receiver R, Figs. 154 and 155, which is 5 ft. in diameter and 30 ft. in length.

158.



159.

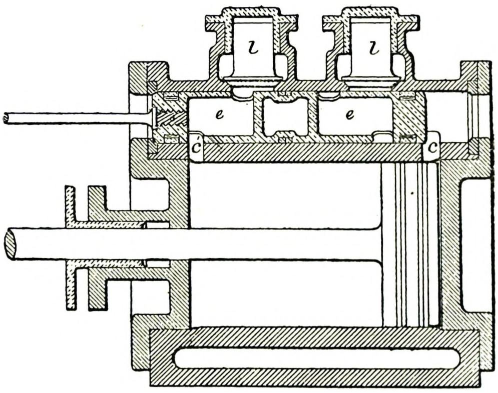


Fig. 158 is of an air-compressor, designed by Richard Schram, of London, and Fig. 159 is an enlarged view of an air-cylinder on this principle, but with two valves. The cylinder *a a'*, in which the air is compressed, is cast in one piece with the cylinder *b*, through which the compressed air is driven at each stroke of the piston *k*, by the openings *c c'*, alternately into the receiver which communicates with the cylinder *b*, by the delivery valve *l*. When the piston *k* commences its backward stroke, the hollow piston *e*, which works in the cylinder *b*, is in the position shown, so that as the air-piston *k* travels, air enters freely through the opening *c'*, the air in the cylinder is driven through the opening *c* into *b*, where, being enclosed in the space *e*, it passes through the delivery valve *l* into the receiver. The piston *k* continues its stroke until close to the back cylinder cover, and as there are no recesses or valves in either of the cylinder-covers, or in the piston itself, it practically forces all the air out of the cylinder *a* into the receiver without loss, a feature peculiar to this compressor. The air-piston *k* and the steam-piston *t* move simultaneously. There is an ordinary slide valve fitted to the steam-cylinder, not shown in the figures; this being reversed, steam enters the cylinder *d*, and, at the same time, passing through the port *n*, reverses the small piston *s*, which works in a separate cylinder on the top on the main steam cylinder.

The rod of this small piston being connected with *e*, causes it to be reversed simultaneously with *s*, and allows free air to enter *a*. at the same time a communication is made between the cylinders *a* and *e*, for the air which is to be compressed at the next stroke. A corresponding operation takes place during the forward stroke. When the air-piston *k* and the steam-piston *t* have arrived at the end of their forward stroke, the steam admitted into the steam-cylinder *d* enters through the port *n'*, reverses the small piston *s*, and with it *e* is reversed, and the machine will be again in the position shown. When this compressor is not driven directly by steam, *e* is worked by mechanical means from the crank-shaft. Any compressed air remaining at the end of each stroke in the space in *e* cannot be lost, for on opening the passage *c* to the free air and the cylinder *e*, *a* still cuts off the cylinder *b* from communication with the free air, and effects a similar purpose at the other end. Thus *e* is never in communication with the atmosphere, but only with that part of the main cylinder *a* or *a'* in which compression is going on. The delivery valve *l* moves vertically, and the air in the receiver being admitted to its upper surface, it closes freely by the back pressure and its own weight. A modification of this arrangement, especially in the larger sizes of these compressors, is sometimes made; this consists in having the space *e* divided into compartments, as in Fig. 159, with two delivery valves. The air retained in the space *e*, which in large machines would act detrimentally on the reverse stroke, is here reduced in amount by one-third, while the same advantage is obtained as when the single delivery valve is used, neither of the two delivery valves being ever exposed to the free air. By effecting the inlet in the manner described, the free air enters the cylinder perfectly cool. It has not to pass through narrow valves with the attendant friction and heating, and thus a full volume of cold air at the atmospheric pressure fills the cylinder and is compressed at each stroke. Another advantage obtained by dispensing with inlet valves, is the avoidance of a partial vacuum at any part of the stroke. When the inlet is effected by means of valves, these valves generally open by suction, so that a partial vacuum is of necessity produced before the free air is admitted into the cylinder. When springs are used to close these valves the whole cylinder can never be filled with air at full atmospheric pressure, and consequently part of each stroke of the piston is ineffective, serving merely to bring the air which is to be compressed to atmospheric pressure. Should the inlet valves open and close by friction of the piston-rod or by suction alone, then part of the air, instead of being compressed, is lost at the commencement of each stroke, being driven out of the cylinder before the valves are properly closed.

As the consumption of air varies with the work performed by the machine supplied, it is necessary to have a reservoir, in which sufficient air can be stored to render the variation in consumption inappreciable. Boilers and tanks are frequently used as receivers. Sometimes the base-plate of the compressor is constructed as a receiver, but this plan does not give sufficient capacity. The receiver should be provided with outlet and water-discharge cocks.

To convey air to the work, both cast and wrought iron pipes are used. A flange is cast on the pipes, and an indiarubber washer secures the joint between the flanges. In some cases one flange is grooved and a bead formed on the face of the other. Where lightness is required, wrought-iron piping is used, with carefully-fitted flanges. Each flange is fitted solid by interposing in a groove in the flange, a copper ring between the flange and the pipe; by brazing, the flange, ring, and pipe form an air-tight joint. Considerable lengths of piping require means to be provided for the expansion and contraction, caused by variation in temperature.

W. Daniell, in a paper read before the Institute of Mechanical Engineers in 1874, gives some important details of experiments, undertaken for the purpose of determining the proportion of useful effect obtained from compressed air. The machinery employed in these experiments consisted of a 16-in. double-cylinder steam-engine having a stroke of 30 in., and an air-cylinder of the same diameter, placed behind each steam-cylinder, and on the same piston-rod of 2½ in. diameter, the general construction being similar to that of the Fowler compressor just described. This compressing engine was mounted on a receiver 5 ft. in diameter and 24 ft. in length, which served as a bed-plate. The engine worked by the air was an ordinary semi-portable engine, having two 10-in. cylinders with 12-in. stroke, and a common slide valve cutting off at three-fourths stroke. The air from the receiver was taken into the multitubular boiler of this engine, which formed a second receiver, and was there cooled to the same degree that it would have been if taken through a long length of pipes, though probably there was less friction. The temperature of the air in this receiver was never more than 5° Fahr. above that of the atmosphere. This air-engine worked a friction brake, and indicator diagrams were taken from its cylinders while disconnected from the brake, and also while running with the load on the brake. The force expended in compressing the air was ascertained by diagrams from the steam-cylinders of the compressing engine. The diagrams were taken at five different pressures of air and steam. Three experiments were made at each pressure, and the mean results taken. These mean results are given in the following Table. The duration of each experiment was about twenty minutes, and no greater variation of air-pressure than ½ lb. to the square inch took place in the receiver during any one experiment. The air-pressures for each set of experiments were respectively 40, 34, 28½, 24, and 19 lbs. to the square inch above that of the atmosphere; 40 lbs. being the maximum generally considered advisable in practice, it was deemed unnecessary to go beyond this. From the detailed statement given in the Table, it will be seen that the power required to compress the air being ascertained by the steam-cylinder diagrams, the percentage of useful effect yielded by the air-engine at the five different pressures of air was as follows;—

	Per cent.		Per cent.
Air pressure 40 lbs. gave useful effect	25·8	Air-pressure 24 lbs. gave useful effect	34·9
„ „ 34 „ „ „ „	27·1	„ „ 19 „ „ „ „	45·8
„ „ 28½ „ „ „ „	28·5		

The useful effect is arrived at by adding to the power absorbed by the brake, the power required to work the unloaded brake, the result being ascertained by taking indicator diagrams from the engine driving the loaded brake, and deducting from those diagrams the power required to work the engine alone.

Pressure of air in receiver in lbs. to the square inch above atmosphere	40·0	34·0	28·5	24	19
Mean effective steam pressure in compressing engine in lbs. to the square inch	26·3	25·1	21·5	19·7	16·6
Piston speed in compressing engine in feet a minute	190	155	140	110	60
Mean effective pressure in air-engine in lbs. to the square inch	35·6	29·8	24·7	21·0	17·0
Piston speed in air-engine in feet a minute	108	104	104	108	88
Circumferential speed of brake-wheel in feet a minute ..	936	901	901	936	763
Load on brake in lbs.	448	364	280	224	140
Indicated H.P. from compressing engine steam-cylinders (A)	59·4	46·2	35·8	25·8	11·8
„ „ air-engine cylinders	18·3	14·7	12·2	10·8	7·1
H.P. by load on brake .. .. (B)	12·7	9·9	7·6	6·4	3·2
Indicated H.P. required to drive unloaded brake .. .. (C)	2·6	2·6	2·6	2·6	2·2
Total H.P. yielded by air-engine (B + C)	15·3	12·5	10·2	9·0	5·4
Percentage of useful effect $\left(100 \times \frac{B + C}{A}\right)$	25·8	27·1	28·5	34·9	45·8

The same writer gives, in the following Table, the theoretical useful effect obtained from the compressed air at the five different pressures employed in the experiments, as compared with that which would be obtained from the direct employment of steam, having the same initial pressures as the compressed air, cut off at three-fourths stroke. The calculation is made on the assumption that, in each case, the air is compressed by the employment of 70 lbs. steam, cut off at one-fourth stroke in a non-condensing engine. The theoretical mean effective steam pressure is then 35·8 lbs. to the square inch, and the weights of 1 cub. ft. of 70 lbs. steam being taken at 0·183 lb., the theoretical useful effect to the pound of water evaporated is $\frac{35 \cdot 8 \times 144 \times 4}{0 \cdot 183} = 112 \cdot 682$ foot-pounds in the steam-cylinders of the compressing engine. The percentage of useful effect realized in the air-expanding engine is taken from the actual results of the experiments given in the preceding Table. Thus in the case of compressed air at 40 lbs., it is shown in that Table that the percentage of useful effect actually obtained is 25·8; consequently the theoretical useful effect of the air at 40 lbs. is $112 \cdot 682 \times \frac{25 \cdot 8}{100} =$ 29·072 foot-pounds to the pound of water evaporated, and for the other four pressures of air the corresponding results are similarly arrived at, as given at E in the Table. The theoretical useful effect that would be obtained from the direct employment of steam at the same initial pressures as the compressed air, and cut off at three-fourths stroke, is given at G in the Table; it is calculated from the following formula, in which N denotes the number of times the steam is expanded, that is, the ratio of the final volume to the volume at the point of cut off. In the experiments the cut off being at three-fourths stroke, N = $\frac{3}{4}$, and the hyperbolic logarithm of N = 0·288. The weight of the initial steam a cubic foot, at the different pressures, is given in the Table, and the initial pressure is in the formula expressed in pounds above the atmosphere.

$$\text{Useful effect of steam} = \frac{144 \times \left\{\frac{\text{initial pressure} + 14 \cdot 7}{N} \times (1 + \text{hyp. log. } N) - 14 \cdot 7\right\} \times N}{\text{Weight of initial steam a cubic foot}}.$$

It will be seen from the results tabulated, that the relative advantage derived from the use of compressed air is greater at the lower pressures.

Pressure of air in receiver in lbs. to the square inch above atmosphere	40·0	34·0	28·5	24·0	19·0
Weight of 1 cubic foot of steam, in lbs.	0·123	0·110	0 099	0·090	0·79
Theoretical useful effect of air for each lb. of water evaporated, in foot-pounds .. .. (F)	29·072	30·537	32·114	39·326	51·608
Theoretical useful effect of steam at same initial pressure as the air, in foot-pounds .. .. (G)	59·544	56·453	52·424	48·393	43·392
Percentage of useful effect from air compared with steam $\left(100 \times \frac{F}{G}\right)$	48·8	54·1	63·3	81·3	118·9

Relatively to the economical employment of compressed air, it has come within the experience of the Editor of this Dictionary, that in cooling the air, and letting it expand again, the attainable limit of useful effect is about 50 per cent. In compressing air, the whole of the force exerted in compression appears as heat, and this heat expands the air; so that a larger volume has to be expelled than if the same temperature were maintained. The remedy for this loss consists in injecting a spray of cold water into the compression cylinder, to keep the temperature uniform. In expanding the compressed air, the removal of the ice formed in the exhaust passages of the expansion cylinder, can be effected by the injection of water at the temperature of about 90°. This water, imparting its heat to the expanding air, prevents the formation of ice, and, combined with the injection of cold water into the compression cylinder, increases the percentage of useful effect. The injection of warm water into the expansion cylinder has not been generally carried out, but transmission of power by compression of air would, with this aid, compete with the transmission of power by water.

ANIMAL CHARCOAL MACHINERY.

The most important of the uses to which animal charcoal is applied in the manufacturing arts, is the decolorization of syrup in sugar refineries. Without treating of its action, it is sufficient to state that after a time the charcoal ceases to purify the syrup, but it is found that the properties of the charcoal may be restored by re-burning it, and apparatus for this purpose form, therefore, an important feature in machinery for refining sugar.

The machinery is of two kinds, in one of which the re-burning is effected by passing the char through fixed pipes or retorts, whilst in the other revolving cylinders are employed, combined with appliances for causing the material to travel through the retort, external heat being applied from a furnace in either form.

The common practice in the revivification of animal charcoal is to wash it with water in the same tanks, or charcoal filters, in which it had been placed for the purpose of receiving sugar liquors for filtration, by running water on to the head of the tanks when full of charcoal, and the water by percolating through the mass and out at the bottom is supposed to perform the needful washing. For the further reviving of the charcoal it has been customary to convey it in trucks, after the washing process, to kilns heated by furnaces, in which are placed either upright pipes or rotating cylinders, into which while yet wet the char, as it is termed, is made to descend, and in which it is dried and subsequently burned or calcined. When upright pipes are used in these kilns they are necessarily of considerable size, generally of 5 to 6 in. in diameter if round, or 3 to 4 by 8 to 9 in. if oblong, so that the charcoal, while yet wet and not in a condition to run through small apertures, may not stick in the pipes. The consequence of using such a size of pipe is, that before the red heat from the sides can reach the centre of the mass of char to make it red hot, it is compelled to travel through from 1½ to 3 in. of charcoal forming the exterior portions of the mass, and owing to charcoal being a bad conductor and transmitting heat slowly, the exterior portions are overburned before the interior is burned at all. This overburning of the char is very detrimental, and if carried to a great extent completely destroys it, and fresh char is required. When rotary cylinders are used in charcoal kilns they are made red hot, and as they rotate the coarser or heavier portions of the char roll constantly forward in advance of the mass on to the red-hot surface, and as more or less air enters with the charcoal such exposed portions become decarbonized and spoiled. Subsequently to such re-burning, the charcoal is made to descend while yet red hot into narrow sheet-iron chambers called coolers, where it is cooled by the exterior air impinging on their outer surfaces, after which it is drawn off at the bottom by hand.

A complete plant for treating the charcoal, designed by George Gordon, is shown in Figs. 160 to 173.

160.

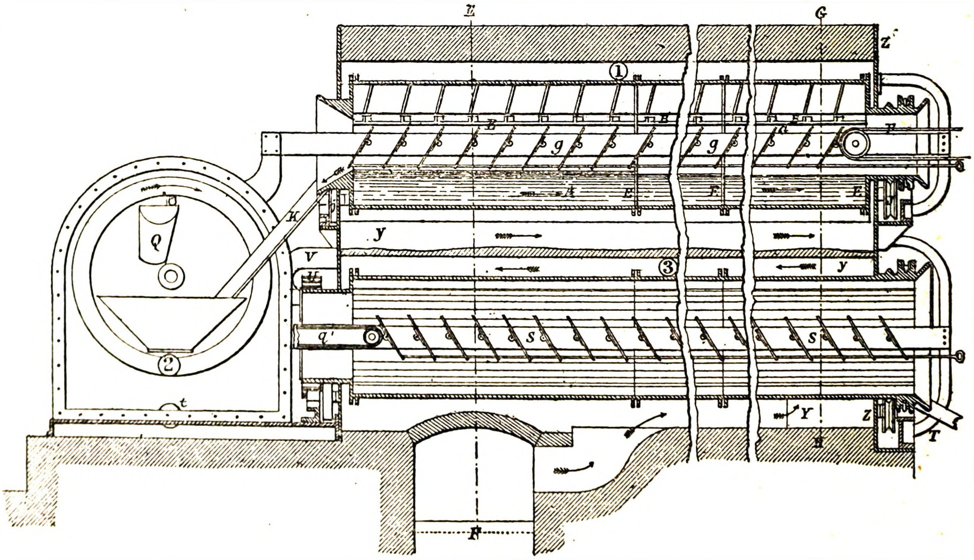
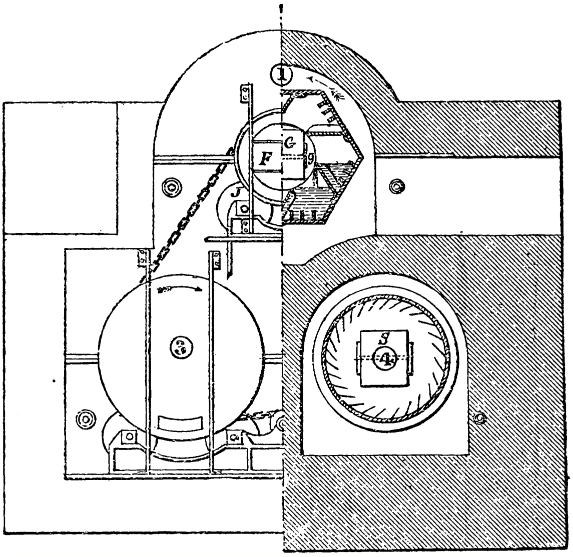


Fig. 160 is a longitudinal section through the washing and boiling cylinder and one of the drying cylinders, together with an exterior end view of the centrifugal sieve.

On the left-hand side of Fig. 161 is an elevation of the driving end, the right side is a section on the line G H of Fig. 160. Fig. 162 shows an elevation of the reverse end with half the centrifugal sieve in section.

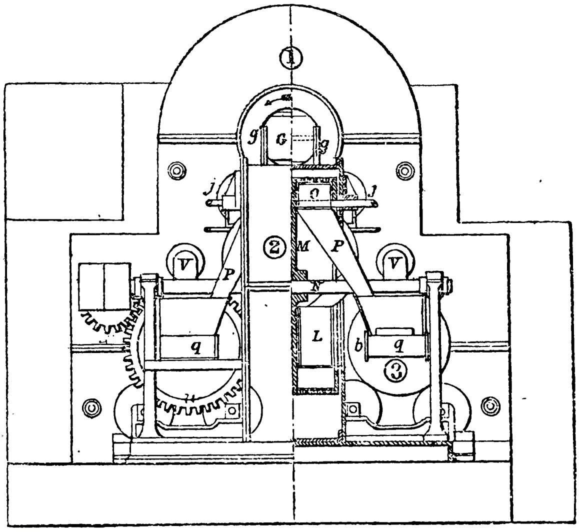
1 is a char washing and boiling cylinder of a hexagonal form, and placed with its axis horizontal and divided into three compartments A A, having six large plates B running longitudinally through each compartment. On the plates are upright ribs, set at an angle, as shown in Fig. 161. Between the plates and on the sides of the cylinder are short ribs, placed so as to throw the char from the feed end towards the exit end. E E, Fig. 160, are flanges dividing the water space into three compartments; the flanges on the extreme left of the figure being the highest. These flanges are successively reduced in height, so that the water may flow over each. F is a feed roller and belt on which the char enters. G is an adjustable feed, consisting of a series of flat plates, hung on centre spindles between two stationary iron side plates *g g*. The flat plates are connected at the bottom edge by a rod, by which the workman sets the plates at any angle, so that the char falling upon them from the plates B, when the cylinder rotates, may shoot forward or backward according to the time he may desire it to be detained in the cylinder; this cylinder has bell mouths, for the exit of the char at one end and of the water at the other; it is driven by a chain, and revolves on grooved rollers J at one end, and flat surface rollers *j* at the other. The sheet-iron shoots K receive the wet char as it issues from the washing and boiling cylinder, and conduct it into the centrifugal sieve hoppers.

161.



2 is a centrifugal sieve, consisting of an annular perforated ring divided vertically through the centre by the plate M, and revolving on the shaft N; this sieve is lined with perforated copper plate or wire gauze; it is provided with hoppers L, which receive the wet char and retain it while the previous charge is drying. The hoppers are open at the bottoms to allow the contents to drop into the sieve. The centrifugal sieve is provided with scrapers O, oscillating on a shaft against the char in the sieve when it requires to be removed. P P are spouts down which the char so removed falls, into the hoppers which feed the drying cylinders **3 4**. The centrifugal sieve is provided with a stationary outer case to collect the water driven off from the wet char, which is conducted away by a waste pipe *t*. **3 4** are drying cylinders, made in three parts for convenience of casting and handling; these are plain cylinders externally, but internally ribs are cast therein, being set at an angle of from thirty to sixty degrees to a line drawn across the centre. Through the centres of these cylinders is an adjustable feed S, which is similar in all respects to the adjustable feed G described with reference to the washing and boiling cylinder **1**. The cylinders **3 4** are provided with feed hoppers Q, at the bottom of which are belts *q q*, revolving on rollers connected to the hoppers and rollers *q′*, attached to the adjustable feed, as shown in longitudinal section of cylinder **3**, and to a similar roller, not shown, in cylinder **4**. T, Fig. 160, is a discharge spout for the char when dry. The cylinders **3 4** are provided with a straight cylindrical mouthpiece, on which is keyed a spur-toothed wheel U, into which is geared the driver pinion; the motion thus obtained on the cylinder **3**, is transmitted to the cylinders **1** and **4** by an endless chain, Fig. 161, working in chain grooves, from a pulley on the cylinder **3** to those on the other cylinders. The cylinders **3** and **4** revolve on grooved rollers at the discharge end, and on plain rollers at the feed end. The vapour created in the process of drying is removed by a pipe in each cylinder, placed over the feed roller at the feed end; this pipe, V, enters the flue, the draught of which carries off the vapour. The exit

162.



ends of the cylinders **3 4** are partially closed by stationary plates, fixed to the frame of the feed **S**, these plates having openings at the bottom to permit the exit of the dry char. The three cylinders are set in brickwork, forming three arches. Fire is applied under the feed ends of both cylinders **3 4**, in the furnace; the current of heat passes them towards the discharge end from **Y**, where it ascends to the upper half of these cylinders to *y*, where it rises into the chamber of the washing and boiling cylinder, traversing it to *v* and heating it, and finally issuing out at the common flue. The ends of the brickwork are closed in by cast-iron plates, to which the carrier rollers are attached, and which are secured by long bolts, running through tubes bedded in the brickwork, and fastening both end plates solidly together. From the drying cylinders the char proceeds either to the vacuum chamber, or to the re-burning kiln.

163.

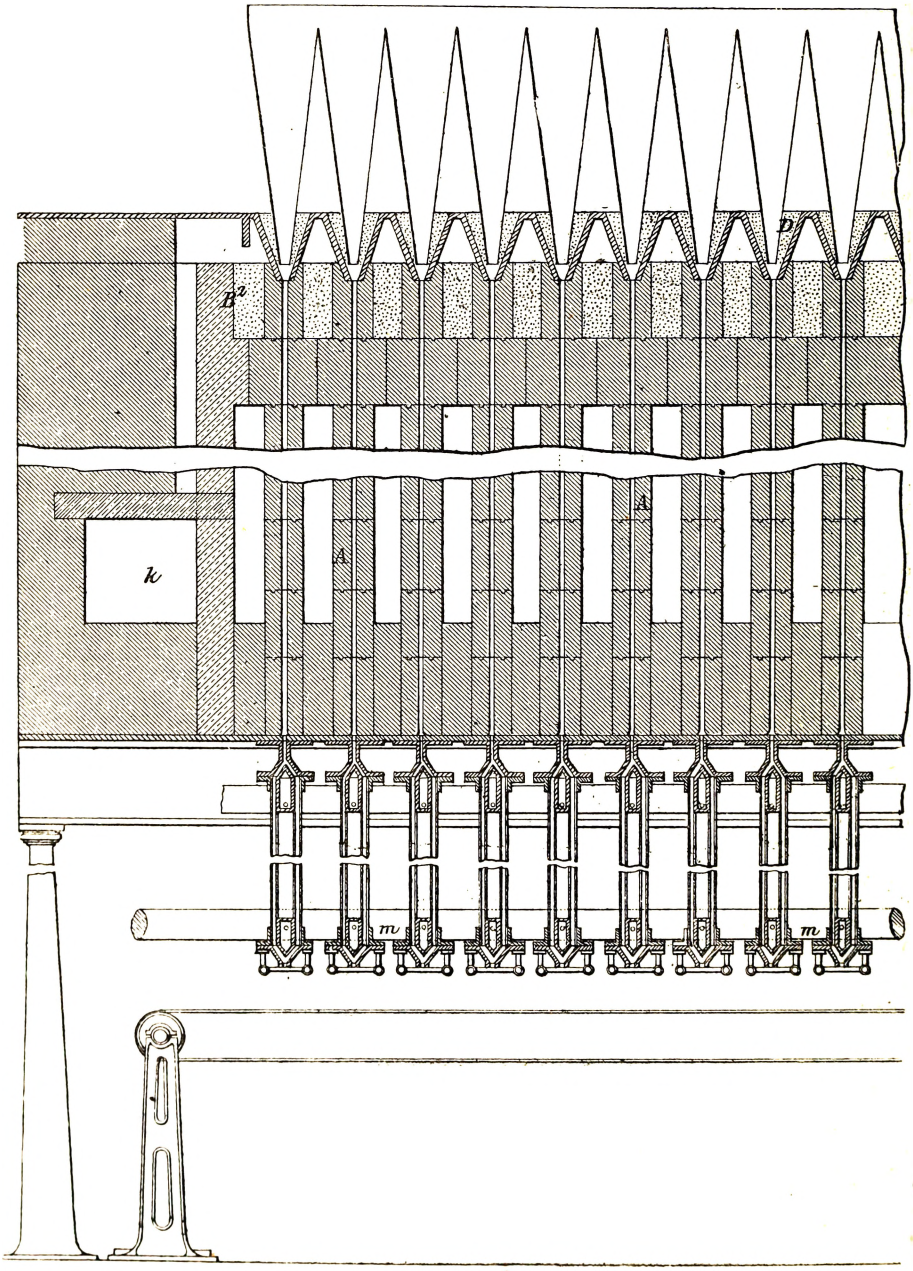
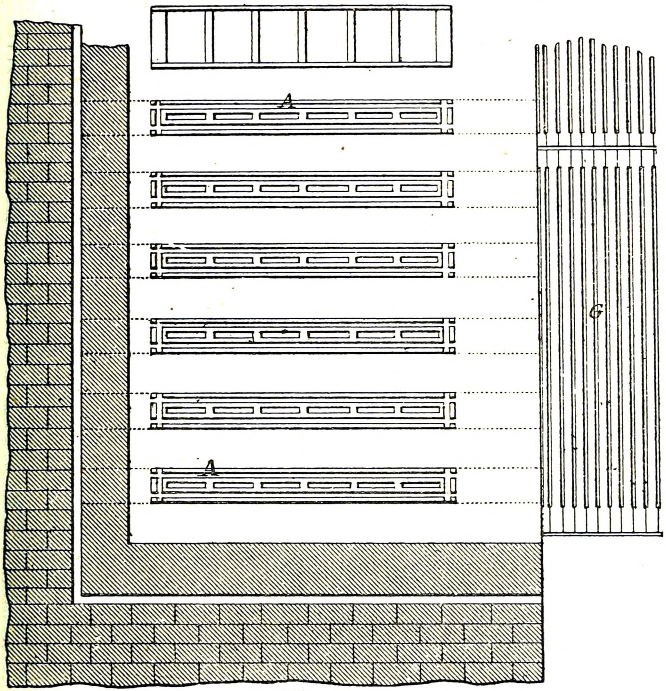


Fig. 163 is a partial section of the re-burning kiln, with its cooling apparatus and the vacuum chamber. Fig. 164 is a sectional plan of one quarter, and Figs. 170 and 171 also illustrate this kiln. Fig. 165 an elevation of one of the retort bricks.

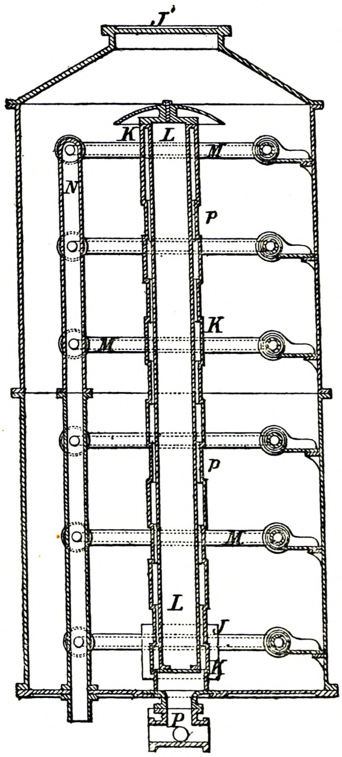
The retorts A are of fire-clay, but may be made of iron, with vertical chambers $\frac{3}{4}$ in. wide 4 in. long, in divisions or bricks about 8 in. deep. The joining surfaces are grooved and ridged. The topmost brick but one, Fig. 163, is made with greater exterior dimensions than the rest, so as to fit together between the retorts and to the lining walls of the kiln at B^2, and to the roof bricks *s*.

165.

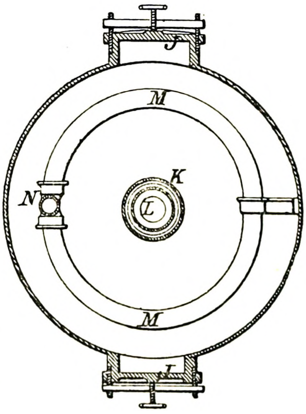


164.

166



167.

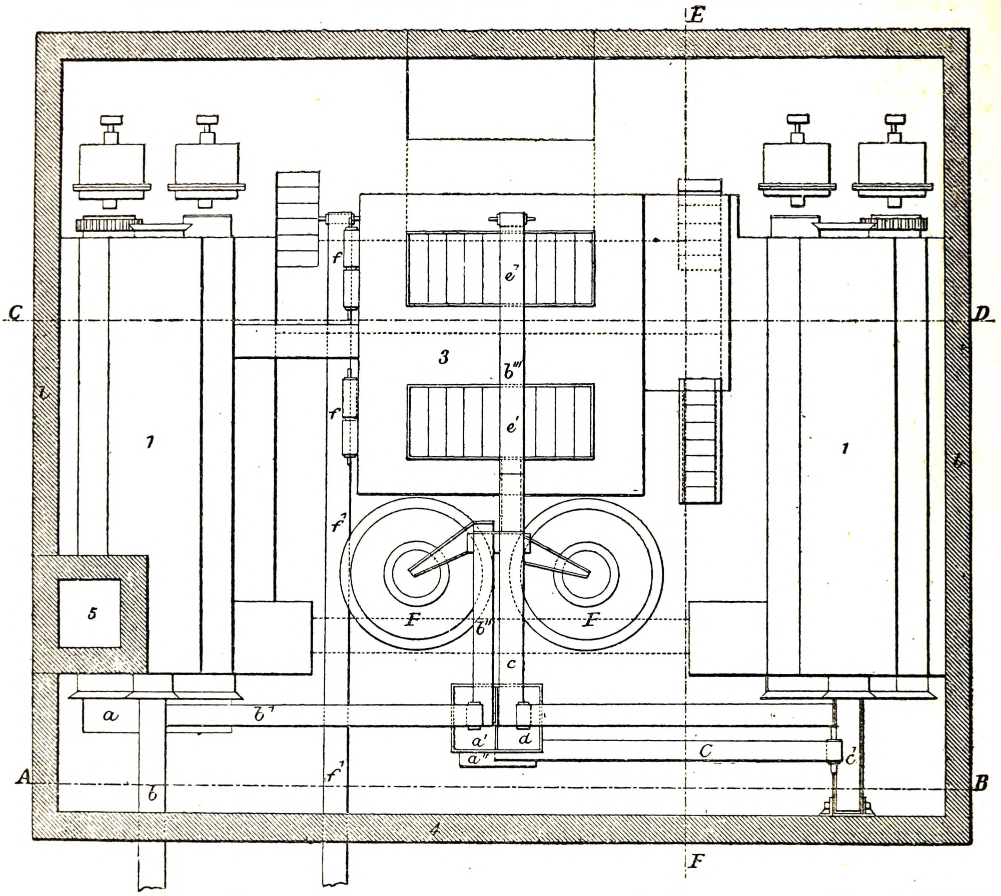


The topmost brick is made to receive the cast-iron hoppers D. The roof of the kiln is formed by hollow fire-bricks *s*, which are supported on the retorts. The hollow brick is covered by some non-conducting materials *t*, and by the hollow cast-iron plates *u*, Fig. 170. There is a lining wall V of fire-brick inside the outer wall of the kiln: between the walls is a 2-in. space. The whole top of the kiln, except the covering of the outer walls, is carried on the retort pipes and the lining wall, so as to secure equality of shrinkage. The furnace G is covered with fire-tiles, which compel the heat to pass up between the retorts at the openings *i*, into the flue *k*, which traverses, within the outer walls, three sides of the kiln. The coolers of sheet iron hang under the kiln; inside the coolers is a water-chamber fixed at top and bottom. Cast-iron pieces *m*, into which water-pipes are tapped, permit cold water to enter at the bottom and exit at the top, the water thus heated by cooling the char, is led away to the washing cylinder 1, Fig. 160. Instead of pipes, this water-chamber may be made of plate iron. The bottoms of these coolers are furnished with slides, which open or shut holes in the bottom casting through which the char makes its exit; these slides being worked intermittently, and so regulated as to retain the char in the pipes the required length of time calculated for burning the char sufficiently.

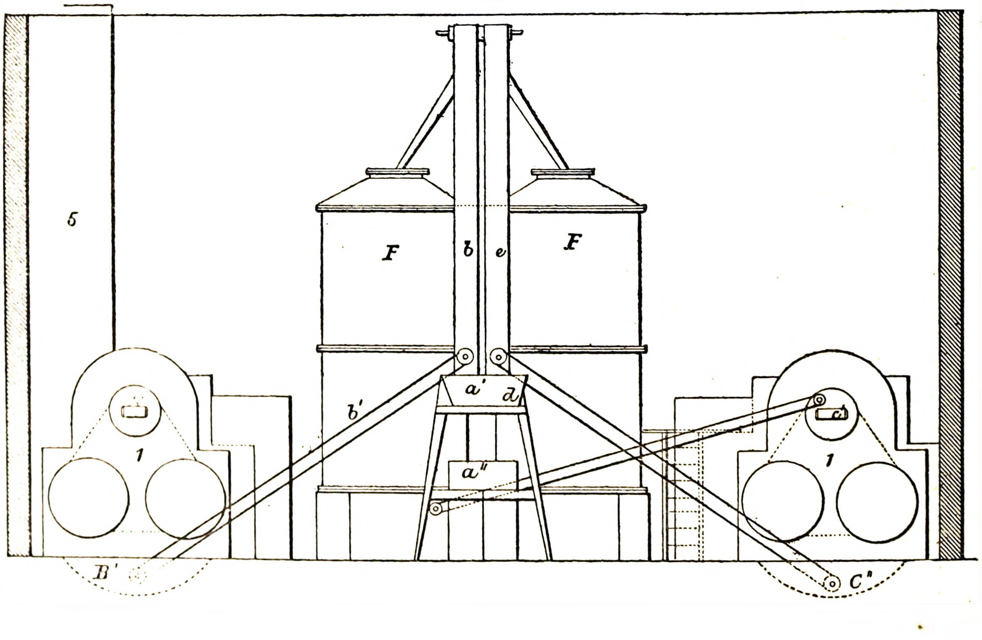
Figs. 166, 167, are a section and plan of the vacuum chamber or acid bath tank, which consists of a plain cylindrical vessel with an opening at the top J', through which the tank is filled; J J are two doors at the bottom by which the char is taken out again; K is a vertical pipe in the centre of the tank, with a perforated part *p* and a solid part K alternately, the perforated part being covered with fine wire gauze. Inside of the pipe K is another pipe L, for the purpose of filling up the space inside when the acid is used. M M are annular pipes, which are perforated with fine holes for distributing through the body of the char an acid or alkaline bath, steam, water, or hot air; N is a vertical pipe through which these pass to the annular pipes; P is a branch pipe to which the air-pump is attached.

The general arrangement of Gordon's apparatus for treating animal charcoal will be seen on reference to Figs. 168 to 171, which represent a portion of the char tank room of a sugar refinery, and a general plan of the structure containing the washing, boiling, and drying cylinders

168.


E
f
e'
C
D
3
b'''
f
e'
i
1
1
i
f'
F
F
b''
c
5
a
b'
a'
d
a''
C
c'
A
b
f'
B
4
F

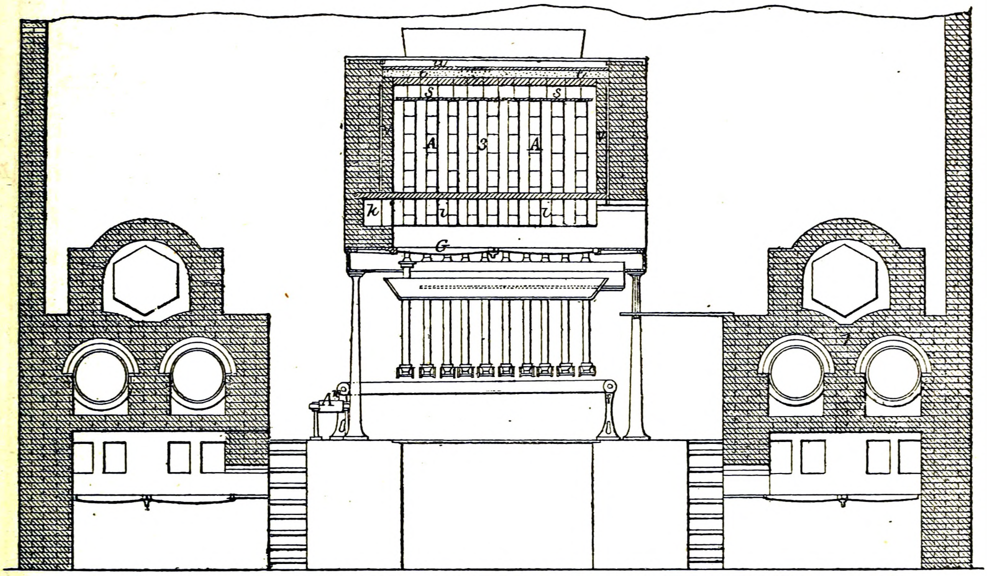
169.


5
F
b
e
F
a'
d
b'
1
1
a''
B'
C''

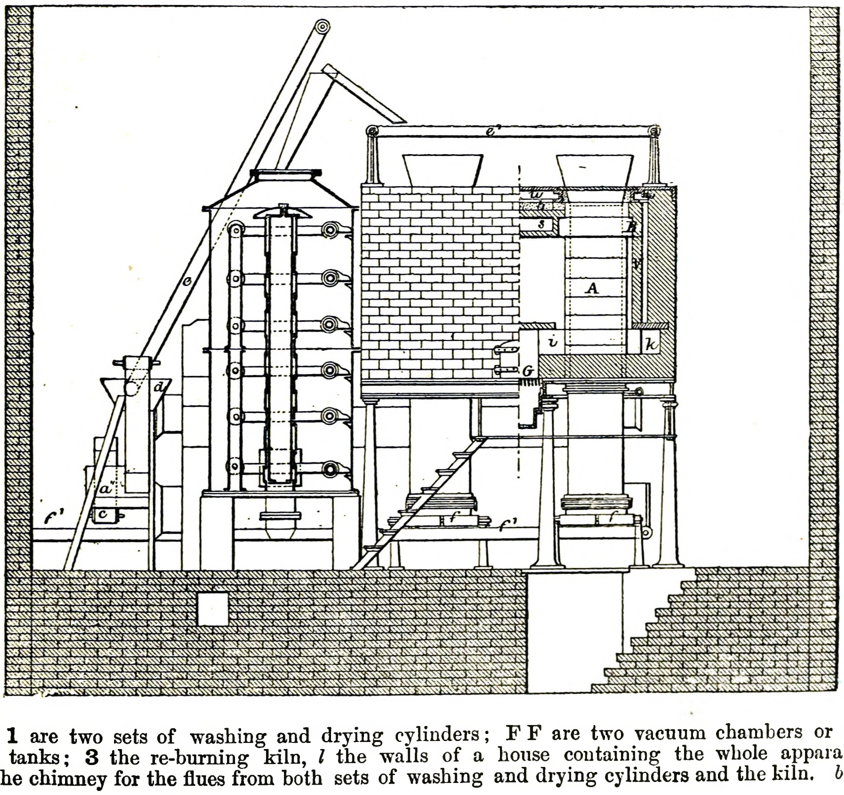
and centrifugal draining sieve, the vacuum chambers and the re-burning kiln and coolers, together with the belts which connect the whole for carrying the char and the graduating apparatus for first feeding the belt, all drawn to a scale of about $\frac{1}{8}$ in. to a foot.

Fig. 168 is a general plan; Fig. 169 a vertical section through the line A B in Fig. 168; Fig. 170 a section through the line C D; and Fig. 171 a section through the line E F. This arrangement is suitable for a refinery where the char may require an acid bath frequently.

170.



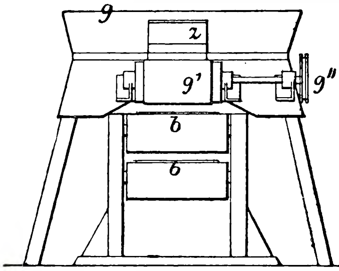
171.



1 1 are two sets of washing and drying cylinders; **F F** are two vacuum chambers or acid bath tanks; **3** the re-burning kiln, *l* the walls of a house containing the whole apparatus; **5** is the chimney for the flues from both sets of washing and drying cylinders and the kiln. *b* is a belt passing through the cistern room, which is loaded with char to a regular thickness by a regulator loading table; the char is carried forward and falls off the belt into the washing and boiling cylinder; when the belt is passing over the roller to return, the char is passed through the washing and drying cylinders, after which it is emptied into a box *a*, in the bottom of which the belt *b'* travels round a roller. The char is carried by the belt *b'* to the box *a'* into which it falls while passing over the roller; at the bottom of this box is a roller over which a belt *b''* passes; the char is again carried by the belt *b''* until it falls into the shoots in passing over the roller at the top, and descends into either acid tank F, or on to the belt marked *b'''*, which feeds the kiln **3**. After the vacuum and the acid bath have been applied, and the surplus acid having been pumped or drained off, the char is taken out at the bottom and placed on the table *a''*, in the bottom of which is a regulating feed which loads the belt C, which latter carries the char until it falls upon the belt *c'*, while passing over the roller; the belt *c'* now carries the char into the second set of washing and drying cylinders, where the acids and salts of lime are washed out and the char again dried, when it falls into a box C,'' Fig. 169, from which the char is carried by the belt up to a box *d*, which is separated from *a'* by a central division. At the bottom of the box *d*, the belt *e* passes over a roller, and carries the char up until it passes over the roller and falls down a shoot on to a belt; over this belt are two dividers or scrapers *e' e'*, which cause the char to fall in equal quantities on each side of the kiln; the char having passed through the kiln, falls from the coolers on to belts *f*, under the kiln, which carry the char and let it fall on to the belt *f'*, this carries the char back to the cistern room.

Figs. 172 and 173 are of an adjustable feed table for loading a carrying belt to a regular thickness of char. *g* is a hopper, having for its bottom a belt moved by rollers *g'*, which are driven by a rope pulley *g''*; this belt has on its surface vertical cross bars, which catch the char and impel it forward until it drops on the carrying belt *b*, shown in the general plan, Fig. 168. A slide *z* in the end of the hopper, above the belt, may be raised at the will of the operator, so as to permit more char to move forward with the belt than the vertical cross bars actually catch; the feed may also be regulated by driving the belt-pulley *g''* faster or slower.

172.



173.

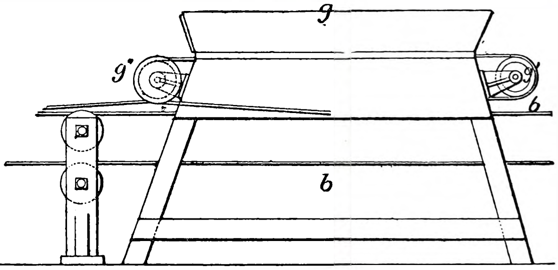


Fig. 174 is a view partly in section and partly in elevations of two retorts, coolers, and accessories as arranged by Buchanan and Vickess; the main object in these retorts is the carrying off the gases evolved by the re-burning, but they also burn the char very equally.

a is an internal pipe with diagonal holes *b* for carrying off the gases formed during the re-burning; *c*, hoods serving to turn the charcoal during descent, to collect the humid gases eliminated, and to keep the holes or perforations *b* free for the passage of such gases into the pipe *a*; *d* is a pipe for conveying the gases from the pipe *a* to the flue or chimney. The charcoal is fed through the opening *e*, and after being burned whilst descending through the retort *e*, is received by the coolers and delivered to the measuring boxes *g*; *h* are steadying pieces for preventing the charcoal during descent from sticking between the retort and its perforated tube; the space for charcoal increases in transverse section from the top downwards.

178.

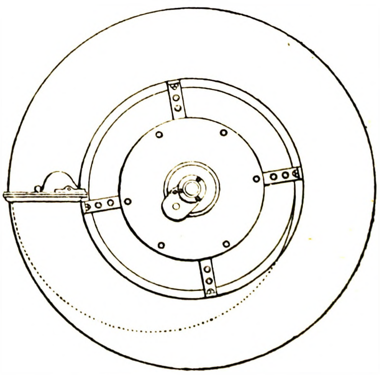
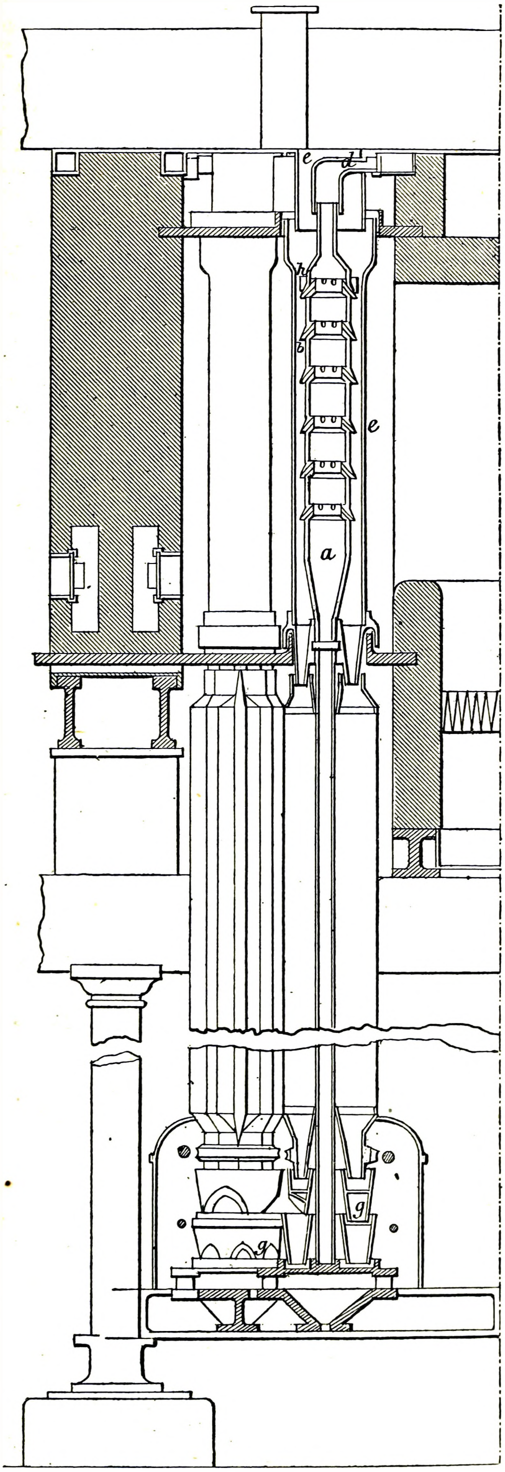


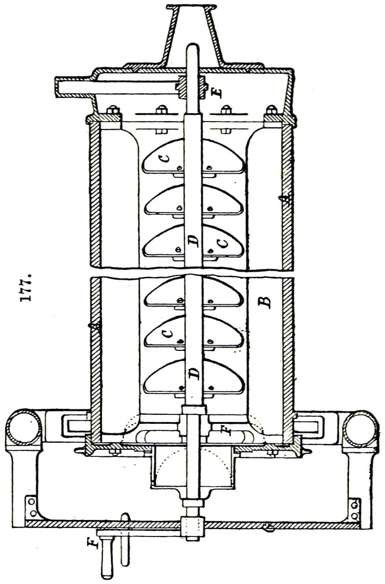
Fig. 175 represents a longitudinal vertical section; Fig. 176 is a transverse vertical section; and Fig. 177 a sectional plan of a mode of traversing the charcoal through the retort during re-burning, introduced by J. F. Brinjes, in 1867. The general arrangement of these retorts in the furnace is similar to that at p. 104 of this Dictionary.

A is the body of the retort, and B B are the longitudinal ledges serving as elevators, which are cast on the interior of the retort. C C are inclined deflecting plates secured to the stationary shaft D, which is supported in a central position by brackets E, at each end of the retort. F is a crank-handle fitted on to the outer ends of D, by which the position of the shaft, with its deflecting plates, may be readily adjusted to give the desired speed of traverse of the substances through the retort. For this purpose a quadrant G is employed, having holes made therein, and the handle F is fixed at any given position along the quadrant by the aid of a pin *f*, passed through the handle and inserted into one or other of the holes made to receive it. The substances to be treated are fed into the retort from a feeding hopper at H, and are discharged at the opposite end of the retort, either into a second retort, or into a volute cooler I, seen in elevation, Fig. 175, and in plan, Fig. 178. The deflecting plates C, Figs. 175 to 177, are shown at their greatest angle, but if the shaft D be turned more or less within an arc of 90°, any variation of this angle with a horizontal plane may be obtained, until by bringing the deflecting plates into a vertical position, they would cease to act as deflectors, and would allow the material to fall from the ledges

174.



177.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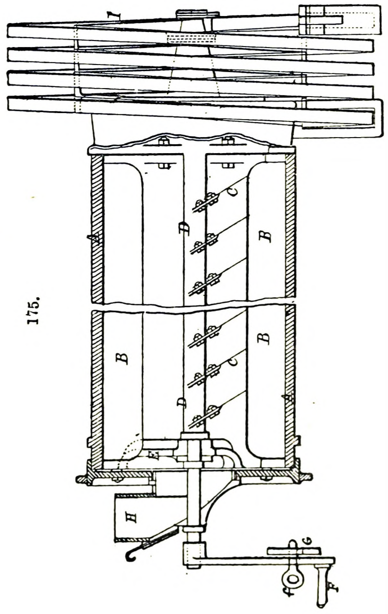
F

175.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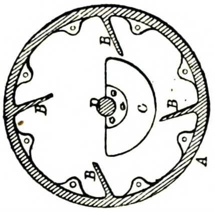
F

176.



B, direct on to the bottom of the retort, in which case there would be no progression. Instead of fixing the plates C to the shaft D, and turning that shaft in its supports, in order to vary the acting angle of the plates C, they may be hinged to the shaft, and their angle varied by a longitudinal rod in connection with the series of hinged deflectors.

The retort in Figs. 179 to 182, which relate to a method of re-burning animal charcoal, devised by P. T. Goodwin, is constructed of cast iron, and is divided into two internal longitudinal chambers by means of a diaphragm of cast iron which is placed in the interior of the retort; if the retort is made of a corrugated form, the corrugations form a series of grooves extending the whole length of the retort, and the diaphragm may be fixed by being placed in two of the corrugations; but for ordinary work it is held in position by means of sockets attached to the interior.

179.

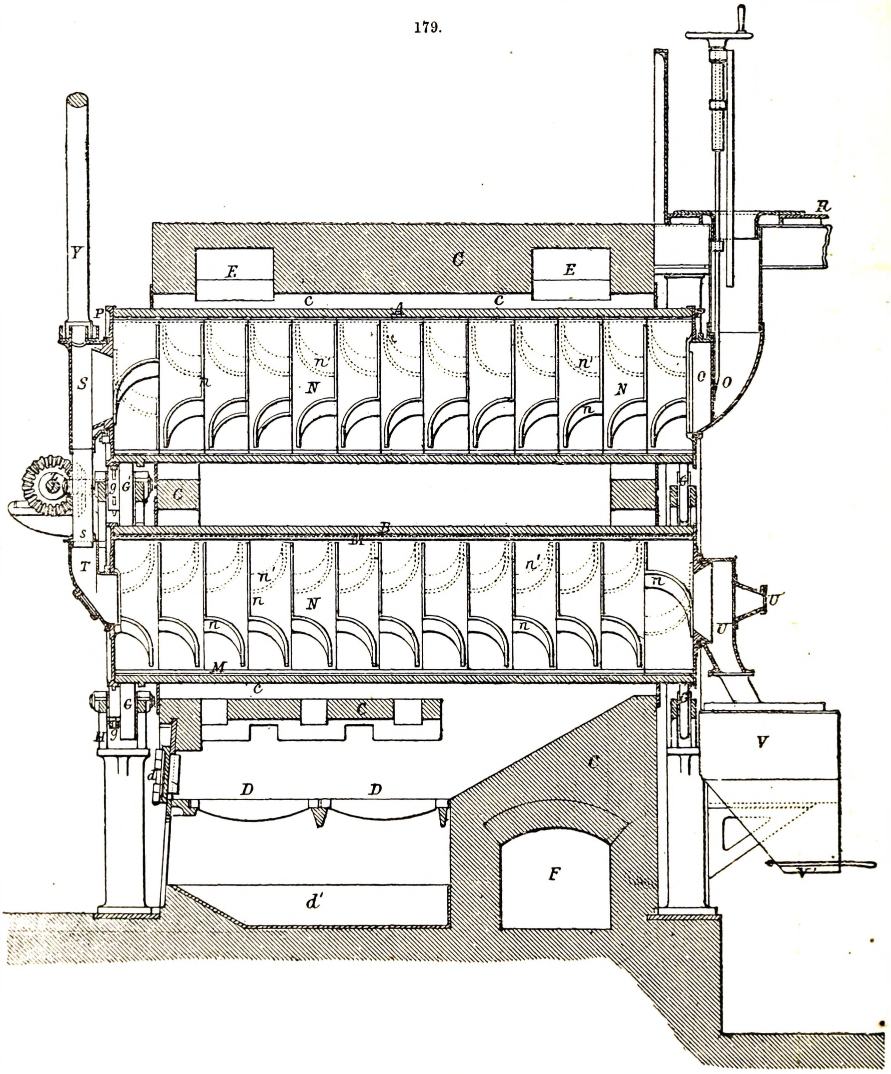
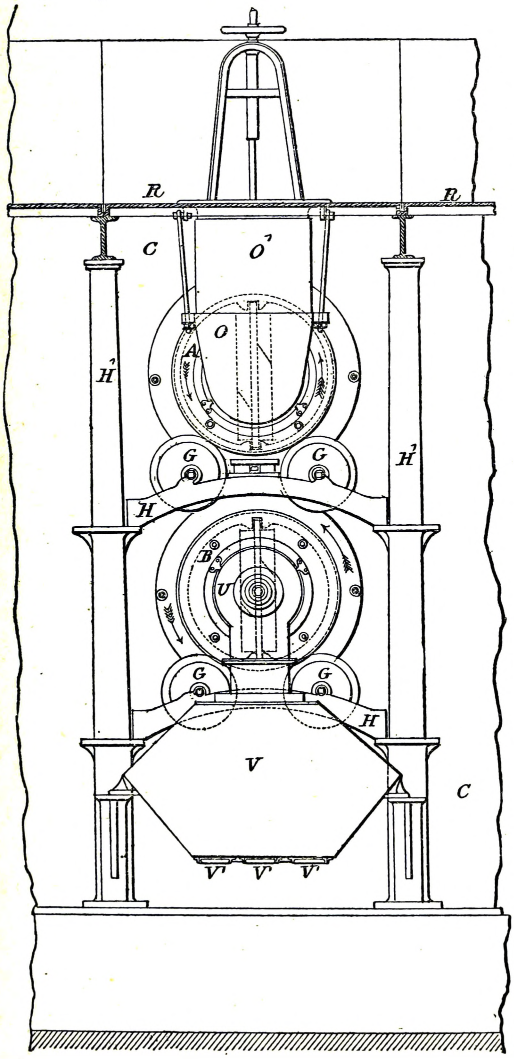


Fig. 180 is a front elevation of the apparatus, and shows the mode of driving a pair of retorts; Fig. 179 is a longitudinal vertical section of the same taken through the centres of the retorts; Fig. 181 is a back end elevation; in these figures the retorts are represented as completely mounted and in working order. Fig. 182 shows a transverse sectional elevation of the retort and division plate.

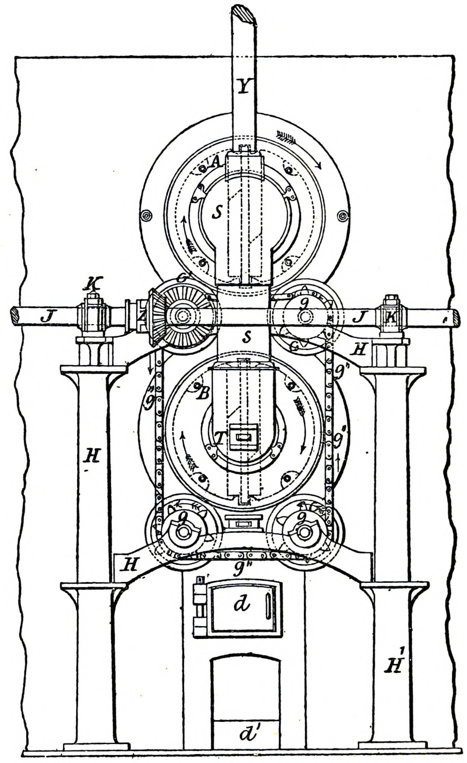
A and B are the upper and lower retorts placed horizontally, and are surrounded by brickwork C C, a clear space *c c* being left round both retorts, for the free circulation of the flame and products of combustion from the furnace D, which escape by the flues E E, into the main flue F leading to the chimney. The retorts are carried on antifriction rollers G G, which are supported by frames H H, fixed to the columns H′ H. The main shaft J J is carried in bearings K K, supported from brackets fixed to the columns H′ H; this shaft is actuated by a steam-engine, and revolves in the direction of the arrows; Z is a mitre clutch-wheel for communicating the power from the main shaft

J to the mitre-wheel Z′, which is keyed on the spindle of one of the rollers on which the retort or cylinder rests; a rotary motion being given to the roller causes the cylinder to revolve; *g g*, Figs. 179, 180, are small cog-wheels keyed fast to the spindles of the rollers G G. An endless flat chain communicates the motion to the rollers supporting the bottom cylinder. The cylinders revolve in the direction of the arrows, and the speed of working may be varied as desired. Each retort is shown with grooves M M, Figs. 179, 182, cast on the interior and extending the entire length, in which are fitted loosely a number of diaphragms, N N; these have projections cast on both sides *n n*, so that when a rotary motion is given to the retort, they turn over and agitate the charcoal, and from the shape of the projections cause it to traverse from one end of the cylinder to the other. The dotted lines show the relative position of the projections on the opposite side of the plate. The retorts are provided with end plates P. A feed hopper *o* is fitted loosely into the end of the cylinder A, and is connected to the charging floor R R, by a pipe. O is a feed valve, shown closed, for regulating the supply of charcoal. The charcoal, after traversing the top cylinder, is discharged through the hopper S which is connected to the bottom feed hopper T by a pipe *s*. The charcoal then passes through the bottom cylinder and is discharged through the hopper U into the cooling box V, which is provided with sliding doors at the bottom V′ V′. U′ is a sight-glass fixed to the hopper for examining the charcoal while being re-burnt. A pipe Y is fitted to the top discharge hopper S, for the purpose of carrying off the vapours or gases, and also the dust and finer particles given off during the process of re-burning, these being taken into a chamber, where the dust and fine particles are deposited. *d* is the fire-door, and *d′* the ash-pit. The division plates N are so arranged in the cylinder that there is an open space between each. The retorts may be used singly instead of in pairs, but the latter is the preferable mode of arranging them; the top cylinder

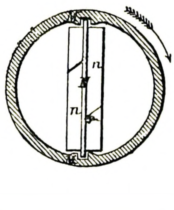
181.



180.



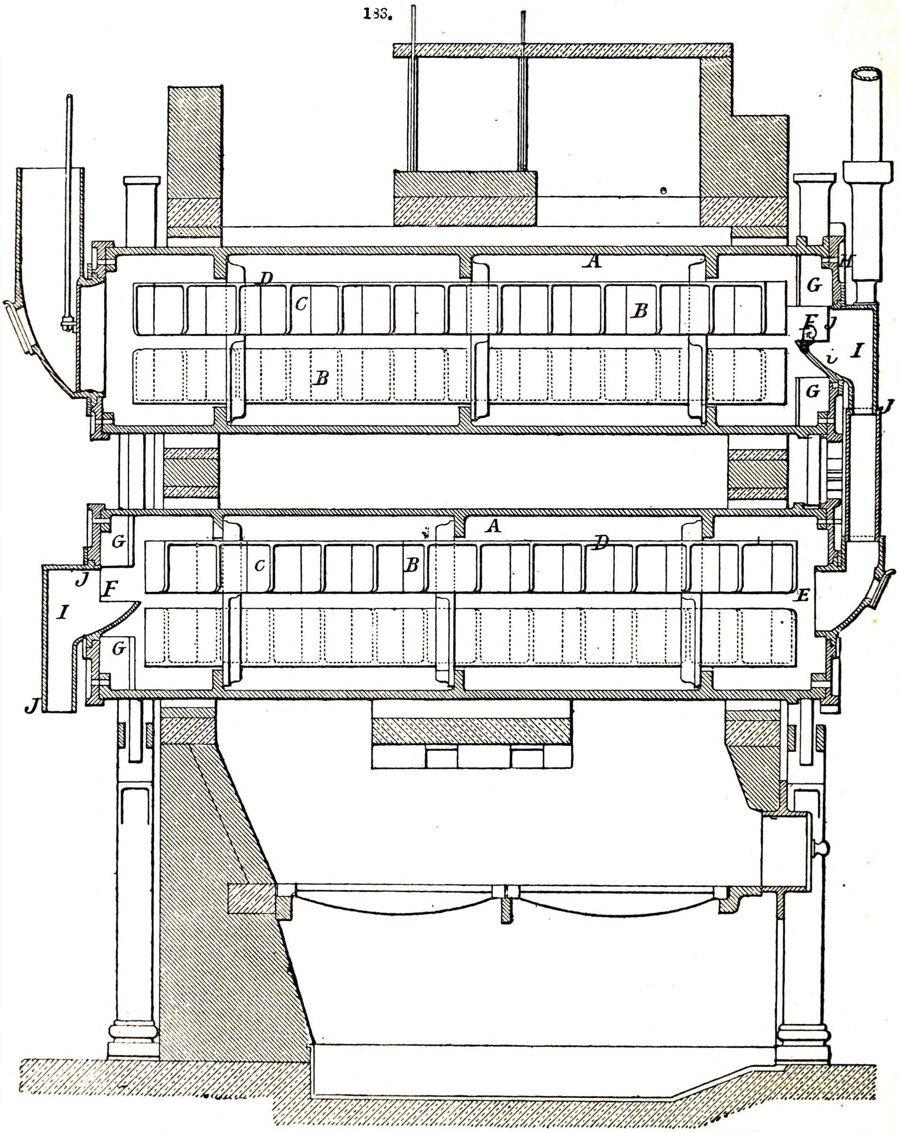
182.



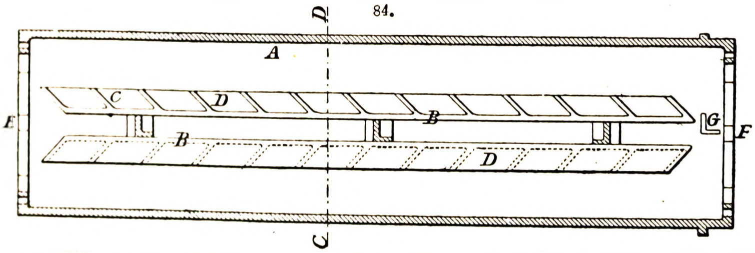
acting as a drying cylinder ensures the charcoal being thoroughly re-burnt in the lower, whilst a saving of fuel is effected.

Fig. 183 is a section of a pair of revolving retorts with Fletcher's arrangement of fittings; Fig. 184, plan of retort; Fig. 185, cross section of same on line C D of Fig. 184.

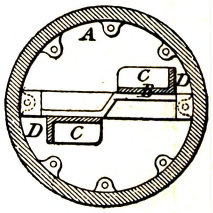
183.



84.

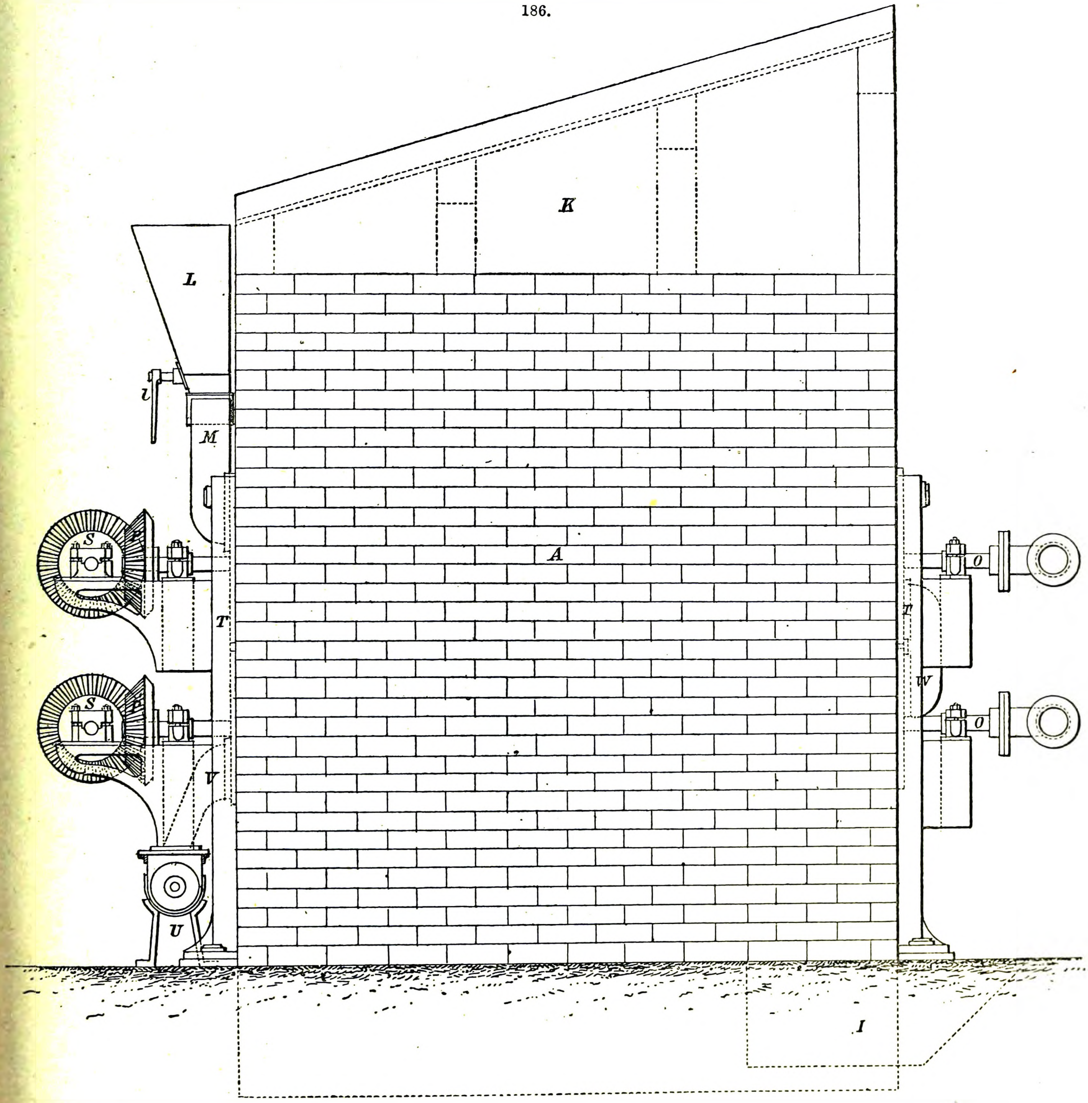


185.



Two longitudinal cast-iron flat bars B B, of nearly the same length as the retort A, are fixed at a short distance from its sides by means of cross pieces, so as to leave a space between their outer edges and the inner sides of the retort. One side of each of the bars B B is fitted with a series of projecting pieces C C, pitched at equal distances apart through the whole length of the bars and at right angles to their edges. These projecting pieces are inclined in the direction of the length of the bars B B, their lower parts being nearer the discharge end, and their upper parts nearer the feeding end of the retort, and serve to propel the charcoal under treatment. The bars B B are each provided with a longitudinal flange D D, of the same height as the projecting pieces and fixed to one of their edges, the nearest to the side of the retort, so as to leave a space between the flanged edge of the bar and the retort, for the passage of the charcoal, the other edge of each bar being near the centre of the retort. The bars B B are fixed at equal distances from each other, and at such an angle that when the retort revolves, the bars B B alternately take up a portion of the charcoal which enters the retort at E, and retain it until they rise sufficiently to make it fall, by its own weight, on to the back of the other bar, when it will be distributed over the surface of the retort. At the

186.

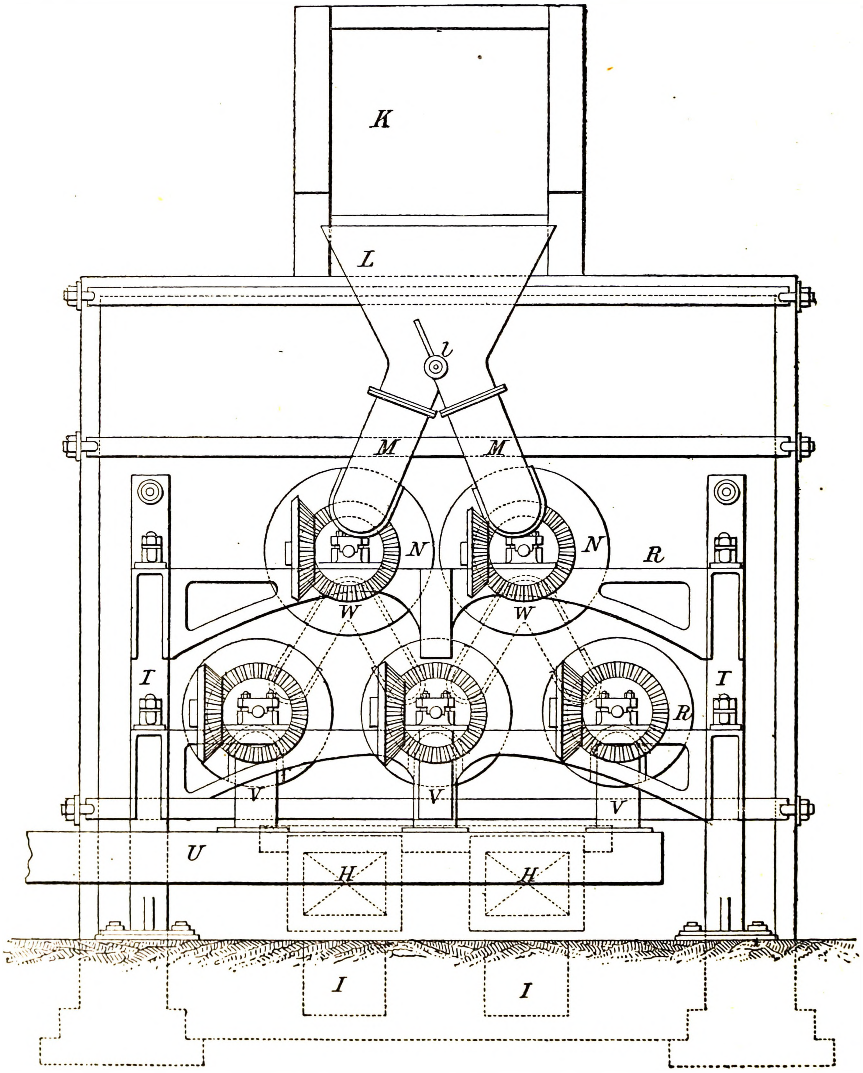


same time the projecting pieces enter the charcoal and carry it forward to the discharge end F, where it is discharged through the hopper I, into the retort beneath, or into the cooler or receiver, as the case may be. The distance to which the charcoal is advanced and the quantity advanced varies according to the angle and height of the projecting pieces. For the purpose of discharging the charcoal after it has been brought to the discharge end of the retort, scoops G, Figs. 183 and 184, are fixed to the end plate H; one scoop only or more than two may be employed. The plate H is fixed to or forms part of the retort and revolves with it; it is fitted in its centre with a discharge or hopper I, round which the retort turns. This hopper consists of a cup or receiver *i* projecting into the retort, and of a circular form where it fits into the end plate at *j*, and of a pipe J of a rectangular form outside the end plate. The charcoal taken up by the scoops G falls into the cup *i*, then passes down through the pipe J into the retort below it, or if this be the lowest retort, into the cooler.

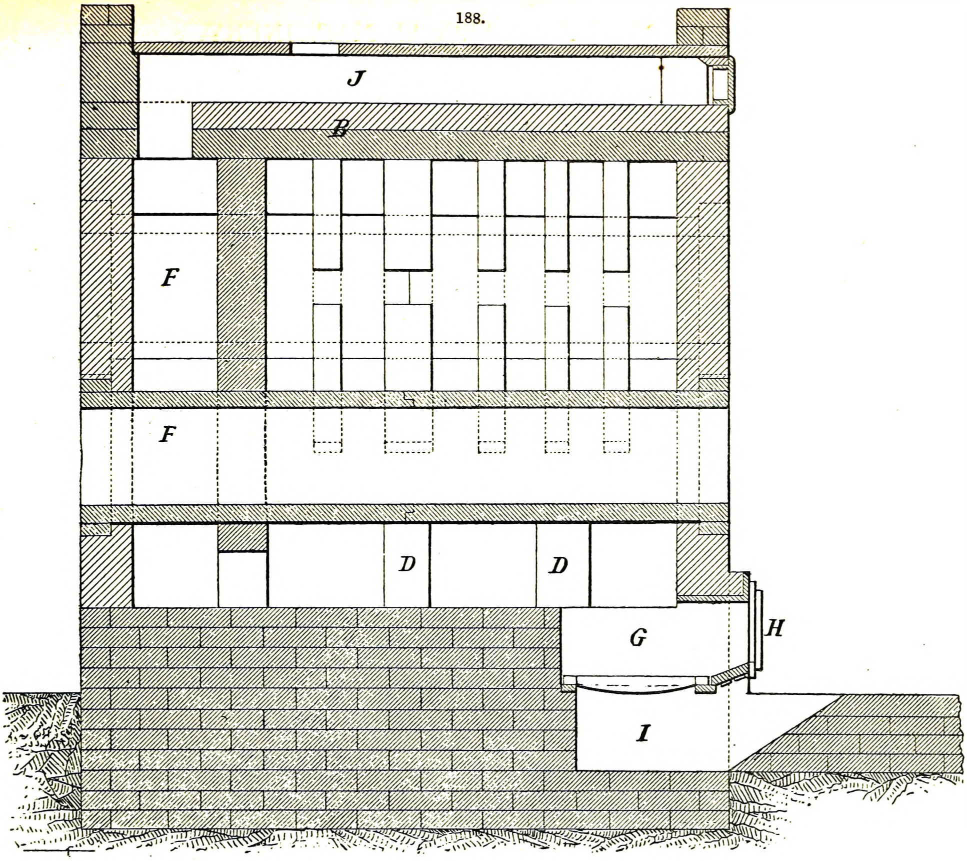
Instead of employing cylinders of cast iron, having within them internal projections arranged spirally, and mounting them in saddles at each end with friction rollers, upon which they revolve freely over the furnace by means of wheels, or the common series of vertical pipes, cylindrical retorts of fire-clay, set in rows, similar to retorts for gas-making, have been proposed by John Denton, and these are set with an arch to cover each series of retorts to be worked together.

In Figs. 186 to 189, relating to Denton's retorts, A is the outer brickwork of the kiln; B, the fire-brick arch; C, the fire-brick linings and walls; D, the supports for the lower series of retorts; E, the fire-lumps, for supporting and framing up the upper retorts upon the lower, and the whole within the arch; F, the retorts; G, the furnaces; H, the furnace doors; I, the ash-pit; J J, the top flues leading to the chimney, or to a heating chamber interposed between the kiln and the chimney; K, an incline shoot, which is intended to be employed for further drying and warming the char, before it enters the receiving hopper L, at the base of which, between the breeches pipes M M, is a shut-off flap valve *l*, with a handle for working it. N N are the covers or end pieces for enclosing air-tight the retorts, O being the shafts or axles rotating within the retorts, at one end of each of which the horizontal tubular junction, or suction, pipes, are shown connected with the exhauster, whilst at the opposite end of each shaft are the mitre bevel-wheels P and P′, the latter being mounted upon horizontal shafts R R, which together with the hollow axles are carried in brackets S S, part of the framing projecting from the uprights T T. U is a horizontal air-tight trunk, which receives the char discharged from the finishing end of each of the three lower retorts through the trunks V. Connecting shoots at the opposite ends of the retorts connect the upper with the lower series.

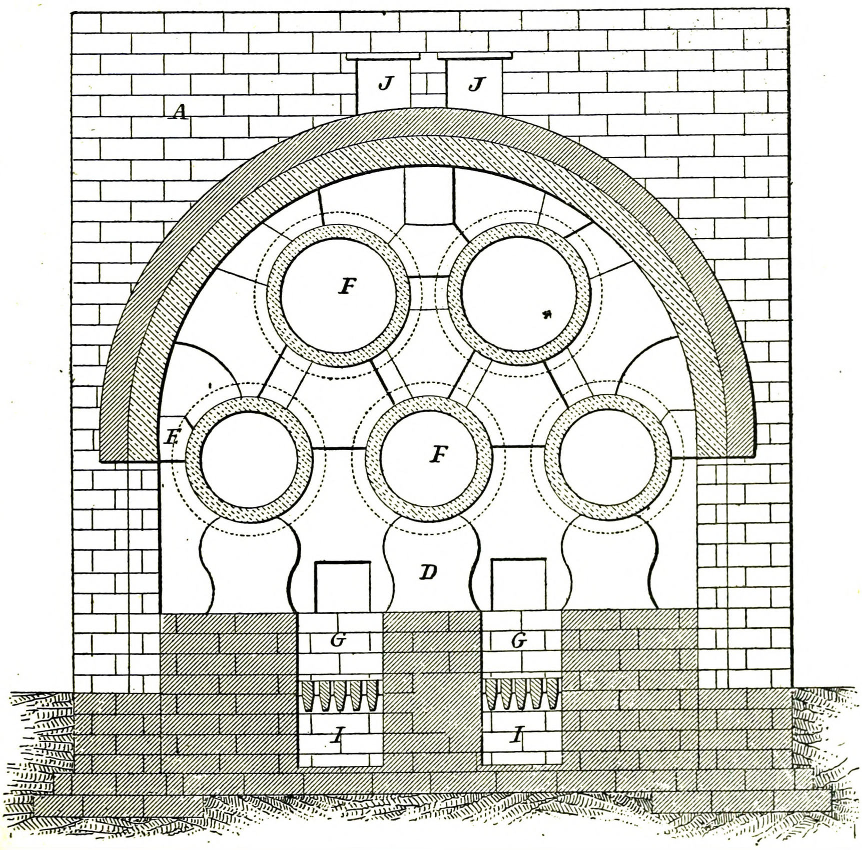
187.



188.



189.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190.

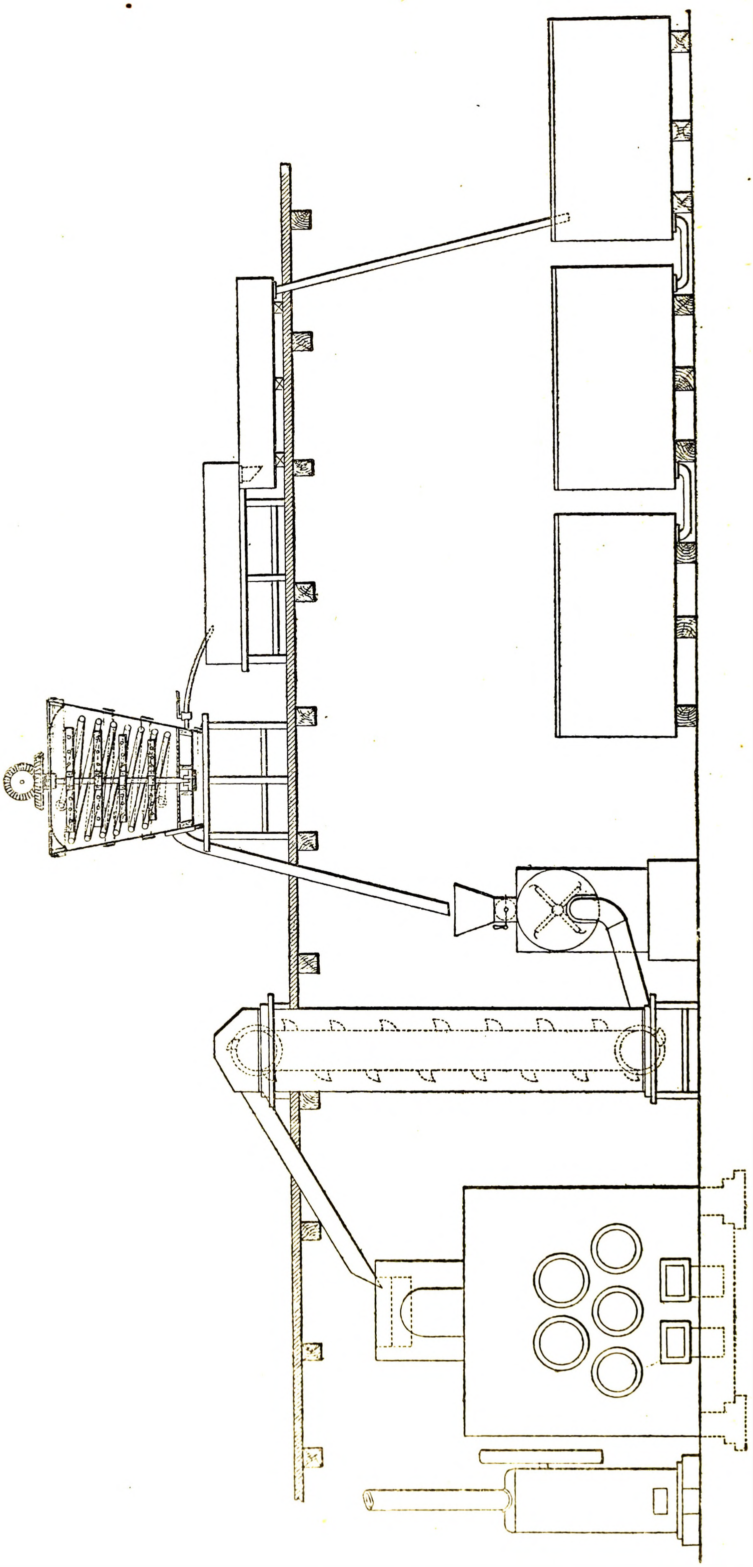
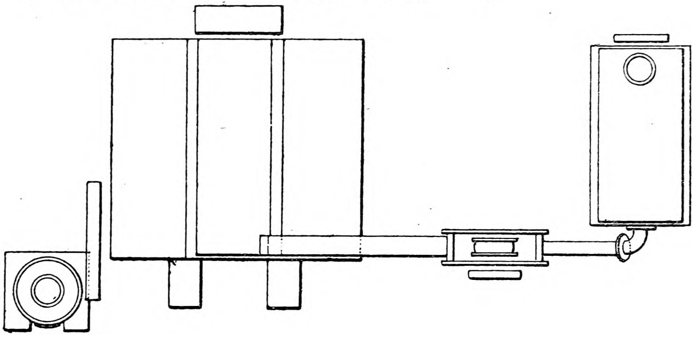


Fig. 190 illustrates a convenient arrangement of the kiln with the apparatus for washing and purifying the char by the humid process, as a treatment preparatory to the re-burning, and the arrangement of these apparatus will be readily understood by reference to the Figs. 186 to 189.

Fig. 191 being a plan of the left-hand portion of Fig. 190.

191.



Within each retort, is placed a shaft or longitudinal axle capable of being rotated or revolved, having upon it a series of vanes or wings arranged spirally like an endless screw, so as to move the charcoal forward from the back or receiving end of the retort to the front or delivery end.

The shafts O are carried in bearings, provided in the covers through and from which they project, and on one end they have a worm wheel.

The shafts are formed of iron tubes with perforations along them; the driving end is plugged, and the opposite end has a stuffing box in which it is free to revolve, connected with an exhauster, and through this the vapours and gases given off during the heating and the re-burning of the charcoal are drawn off, collected, and condensed.

ANTIMONY.

Antimony ores are generally treated either to obtain crude antimony or a regulus, other preparations of antimony in the market being bye-products of manufactures not interested in the direct extraction of the metal. Crude antimony or sulphide of antimony, Sb_2S_3, results from the liquation of grey antimony ore, or stibnite, the residues consisting of the gangue, chiefly quartz or silicate, and containing, after the process of liquation, a high percentage of antimony. The more crystalline is the surface of the metal produced, the higher will be the percentage of antimony in the residues, a fact long known to metallurgists, but eluding their skill to obviate. The following experiments by C. H. Hering, of New York, have been attended with some success, on the large scale, in the reduction of the percentage of metal contained in these residues.

Antimony ores may be considered as;—

Rich ores, containing more than 90 per cent. of sulphide of antimony, and ground, for paint, without treatment.

Liquation ores, with 45 to nearly 90 per cent. of sulphide, in nut-sized pieces, used only for manufacture of crude antimony.

Smelting ores, having the same percentage, and obtained by hand sorting or by dressing. In a powdered state these are roasted in a reverberatory furnace with reducing agents, and used for the manufacture of regulus.

Washing ores, low grade ores, which are dressed. The high grade material obtained must, on account of its fine state, go to the smelting ore.

Metallic antimony may be directly obtained from grey antimony ore by the precipitation process, by smelting the ore with metallic iron, and generally with an addition of Glauber salts and some charcoal powder. In practice the quantity of iron added is generally not more than 40 parts of iron for 100 parts of sulphide of antimony, because in smelting a mixture of sulphide and subsulphide is formed, and because an alloy of antimony and iron is easily absorbed by the metallic antimony. Great care must be taken in adding iron if the ores are impure and contain either lead, copper, or arsenic. The following is an analysis of the material worked;—

	Per Cent.		Per Cent.
Sb_2S_3	20·40	CaO	5·22
FeS	2·87	CO_2	4·10
FeS_2	1·23	Alkalies, and loss	1·69
SiO_2	59·84		
Al_2O_3	4·65	Total	100·00

The first attempt to manufacture metallic antimony from the residues of liquation, on a small scale, was made by smelting in a crucible in a wind furnace, the charge being;—10 lbs. residues, 3 lbs. puddle cinder, 4 lbs. soda. and 50 lbs. charcoal powder. The result was, 1·12 lbs. metallic antimony and 3·32 lbs. of sulphide of iron. The antimony was very pure, and it separated easily from the sulphide of iron. In consideration of the chemical constitution of the residue of liquation, it is necessary to calculate a charge which will easily yield fusible slag in smelting, obtained by increasing the quantity of puddle cinder, an analysis of which showed;—

	Per Cent.		Per Cent.
SiO_2	18·2	Fe_2O_3	14·8
Al_2O_3	2·7	FeO	61·7
Fe	1·0	CaO	·4

The limestone held;—

	Per Cent.		Per Cent.
$SiO_2 (+ Al_2O_3)$	1·50	CO_2	43·34
CaO	55·16		

It follows from the analysis of the residues from liquation that to attain the object in view Sb_2S_3 as well as FeS_2 must be decomposed by iron. Assuming the products to be metallic antimony and FeS, the results of this decomposition are 6·088 parts of sulphur, which for the formation of FeS require 10·654 Fe to be furnished by the puddle cinder, an amount contained in 18 parts.

In the following table line III. contains the sum of I. and II.; in IV. the metallic iron, as well as the oxide of iron in the puddle slag, is calculated as protoxide. Similarly the entire amount of iron in the 18 parts of puddle cinder in 4 has been assumed to have been reduced to metallic iron. From III. it will be seen that the oxygen of the acid exceeds the oxygen of all the bases by 29·753 parts. This oxygen could only be covered for the formation of a mono-silicate by about 350 parts of puddle slag, or by 200 parts of limestone. Such an amount of flux would be enormous, and the addition of limestone would be impossible, because a very high temperature would be necessary to fuse the slag. Experience has taught that slag with numerous bases, such as alumina, protoxide of iron, lime, magnesia, is fusible even as a bi-silicate, when the alumina does not predominate, provided the amount of the other bases is six times as great as that of the alumina. The following charge may be recommended; 100 parts of residues, 150 parts of puddle cinder, and 40 parts of limestone. Or, 100 parts of residues, 140 parts of puddle cinder, and 40 parts of limestone.

The furnace worked regularly, the smelting zone remained in a proper place, the top was cool, and the fumes were thin, blackish, but became glowing red as soon as the charge sank 1½ ft. below the top. In the latter case sulphide of antimony and some oxide of antimony were sublimated. The product obtained in the first experiment was analysed;—

	Slow Smelting.	Rapid Smelting.
Iron	64·31	60·24
Antimony	27·99	31·44
Sulphur	6·61	8·03
Total	98·91	99·71

When the amount smelted was considerably increased and finally doubled, products were obtained holding from 40 to 61 per cent. of antimony. The speiss, or partially reduced metal, grew richer in antimony the more rapid the smelting.

The product of the second tap of the last experiment was taken from the mould too early, so that a liquid part flowed from it. After chilling it was broken, and it was then found that the mass which had been liquid possessed physical properties differing from those of the solid disk. While the former had the appearance of a nickel speiss, the fracture of the latter was like that of fine-grain pig iron. The cavities were filled with a large number of thin bluish crystals. Both products were examined;—

	Not Crystallized.	Crystallized.
Iron	45·12	45·88
Antimony	46·76	46·13
Sulphur	8·81	9·03
Total	100·69	101·04

The residues of the manufacture of crude antimony may be smelted for regulus in a blast furnace, if the dimensions of the furnace and its appurtenances are well selected, and the charge has been made so easily fusible, that at least 14,000 lbs. of residue are put through it in twenty-four hours. In this the product will be a regulus of antimony separating easily from the sulphide of antimony, and requiring only refining in a crucible. The work will prove easier, simpler, and cheaper if products richer in antimony can be added to the residues. The following method may therefore be proposed as one practically valuable for working residues from liquation.

The material is first smelted in a blast furnace 3·3 ft. in diameter and 20 ft. high, as the smallest dimensions admissible. The inner furnace space must be cylindrical, and the blast must be conducted into it by several tuyeres, at least three. The diameter of the nozzle must be so chosen that 500 cubic ft. of air are blown in at a pressure of 6 in. of water. This will permit the reduction of 14,000 lbs. of residues, with the corresponding amounts of fluxes, with a consumption of 14 per cent. of coke. The loss of metal will amount to less than 10 per cent., but condensation chambers are absolutely necessary, because sulphide and oxide of antimony volatilize. It would also be very advantageous to collect the molten materials in a movable hearth. The labour necessary for working the furnace during twenty-four hours would be; 2 smelters, 2 helpers, 2 chargers, 2 machinists, and 2 labourers for moving materials. The consumption of fuel for the generation of steam for 10 horse-power would be about 800 lbs. at a maximum.

The crude regulus produced by the blast furnace contains more or less iron and sulphur, and needs refining. A sample of the raw regulus is taken and examined for the impurities mentioned. According to the amounts present the addition of grey antimony ore is made, and after mixing with soda and Glauber salts, the raw regulus is smelted in a reverberatory furnace.

The refined regulus obtained is, according to circumstances, submitted to refining in a crucible. This may be done directly with the raw regulus if its impurities do not exceed 2 per cent. The regulus is broken into pieces and charged with cinder from refining. If the iron predominate, sulphide of antimony and potash alone are added; if, however, sulphur is present in larger amounts, potash and antimoniate of antimony are the best fluxes. The characteristic star of the antimony

Table for Calculating the Addition of Iron necessary for Precipitating the Antimony and the Amount of Substances remaining to be Slagged in Smelting. (The Iron has been calculated as Metal.)

No.	Weight.	Material.	Substances yielding Slag.					Oxygen in Substances yielding Slag.					Difference of Oxygen.		Iron calculated from Fe_2O_3.	Calculated Production of	
			Bases.				Acid.	Bases.				Acid.					
			Al_2O_3.	FeO.	CaO.	Total.	SiO_2.	Al_2O_3.	FeO.	CaO.	Total.	SiO_2.	Bases.	Acid.		Sb.	FeS.
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I.	100	Residues from liquation	4·650	..	5·220	9·870	59·840	2·170	..	1·49	3·660	31·910	..	28·250	..	14·650	20·514
II.	18	Puddle cinder	0·486	See 13	0·072	0·558	3·276	0·226	..	0·021	0·249	1·750	..	1·503	10·654	..	
III.	118	Sum of I. and II. ..	5·135	See 13	5·292	10·428	63·116	2·396	..	1·511	3·909	33·660	..	29·753	10·654	14·650	20·514

Analyses of the Fluxes. (The Iron calculated as Protoxide.)

No.	Weight.	Material.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
IV.	100	Puddle cinder	2·700	76·307	0·400	79·407	18·200	1·260	16·960	0·110	18·330	9·710	8·620	..	..	..	..
V.	100	Limestone	..	..	55·160	55·160	1·500	..	..	15·760	15·760	0·800	14·960	..	..	..	..

Charge Tables.

No.	Weight.	Material.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
III.	118	Sum of I. and II. ..	5·136	..	5·292	10·428	63·116	2·396	..	1·511	3·909	33·660	..	29·753	10·645	14·650	20·514
VI.	122	Puddle cinder	3·294	93·09	0·488	96·872	22·204	..	..	..	..	..	..	..	..	..	..
VII.	40	Limestone	..	..	22·064	22·064	0·600	..	..	.	..	..	..	..	..	..	..
VIII.	280	Total of charge ..	8·430	93·090	27·844	129·364	85·920	3·930	20·687	7·955	32·572	45·820	..	13·248	..	14·650	20·514

cake, cast after refining, shows the fineness, and consumers can safely judge the quality from this property.

Certain local circumstances, as high price of coke, or absence of motive power, may make working in a blast furnace too expensive. In places so situated that lignite or peat and wood only can be obtained, a reverberatory furnace is to be recommended, with gas firing apparatus and a condensation chamber. The charge should materially differ from that for the blast furnace. The fluxes require to be very readily fusible, so that the charge would soon be covered by a glaze, thus preventing any great volatilization of antimony. If such fluxes cannot be had the condensation apparatus must be very extensive. By firing with gas it is possible to obtain directly saleable oxide of antimony. The antimoniate of antimony settling near the furnace proper should be reduced to metal by coal.

Another method of extracting antimony is by the wet way with hydrochloric acid. Sulphide of antimony dissolves so very readily that any loss of metal caused by incomplete decomposition of the sulphide is impossible. The antimony may be precipitated by addition of water, and sold or reduced for metal; or by other metals, for instance, iron, or zinc. The formation of arseniureted hydrogen should be carefully avoided, as it is one of the most violent poisons. The electrolytical method of reduction may be employed, on account of the high atomic weight of the antimony. The formation of explosive antimony takes place under certain circumstances attending reduction by electrolysis, but is not dangerous. One disadvantage of the wet method is the generation of sulphureted hydrogen in dissolving The latter might be used for precipitating the antimony, the apparatus being similar to those employed in removing arsenic from sulphuric acid.

AXLES AND AXLE BOXES.

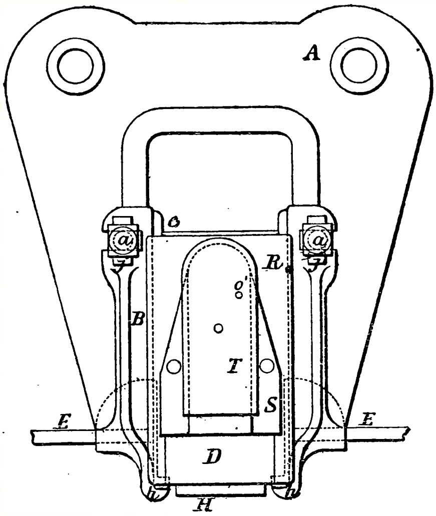
The axle of a carriage, whether for road or rail, is one of the chief structural parts, as upon its strength depends the safety of the whole superstructure, and upon its freedom of working the economy in draught. In any device for making the wear safe and economical there remains the fact that the axle has to bear the weights of the carriage and the load, and that arrangement of axle and box will therefore be the best in which the greatest strength and freedom from wear is given to this part. The following are some of the most generally adopted systems:—

J. N. Smith, of Jersey, America, employs a universal or ball joint used between the lining or bearing and the saddle, one of the objects being to provide for the introduction of these axle boxes into the pedestals now in use. Fig. 192 is a front view of axle box and oiler set in the jaws of a pedestal of a car truck. Fig. 193 is a vertical section. Fig. 194 is a vertical section of the housing and contents. Fig. 195 is a vertical cross section. A is a pedestal of the common form, fitted by drilling holes for the bolts *a a*, which secure the brackets B B to the pedestal. The brackets B B are so formed as to leave a slotted way between them and the pedestal for the flanges on the slide or saddle C to slide up and down in. The slide C is open at the bottom to admit the housing D, and has a spherical seat *c* in its under side to receive the ball *d* on the housing, and form a ball-and-socket joint, the housing being free to follow the motions and direction of the axle in order to avoid cramping and bearing. To prevent the thrusting of the housing out of the pedestal by any sudden and excessive side swaying of the car, lugs or projections are provided on the sides of the housing, which come in contact with the side of the slide C at *f* as soon as the ball *d* leaves the socket *c*, by which the motion of the housing in this direction is confined within the limits of safety. Should sudden derailment of the truck occur, the housing is prevented from leaving the pedestal by the ledges or sides *f* of the slide C striking the tops of the plates *g g*, which form part of the brackets B B.

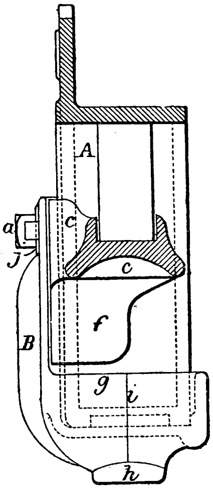
Instead of this provision, the brackets B B are sometimes extended downward, and form hooks *h h*, which will catch the bottom corners of the housing, and keep it in the pedestal. Swells or ridges *i i* are formed on the inner faces of the brackets B B, to permit the housing to swing slightly around a vertical axis, passing through the centre of the ball joint, and at the same time to prevent its swinging or turning around the axis of the journal. The strap E is cut away between the jaws of the pedestal, obviating the necessity which would otherwise exist for its removal. The bolts *a a* are kept from unscrewing by the lock washers *j j*, which are simple sheet-metal washers having projecting portions on their edges, one of which projections is turned up against the bolt head, and another down around the corner of the bracket B. Inside the housing at the top, and resting upon the journal in the usual manner, is the bearing F F. This bearing is of any suitable lining metal, and is cast in a cast-iron shell G, having pins or studs *k k* on its inner surface, which incline towards each other, and lock or dovetail the bearing to the shell or backing G.

When the bearing F F is so far worn away as to require renewal, it is removed and melted off from the backing, and a new one cast in its place. To facilitate the removal, a slope or incline H is cast on the bottom of the housing to receive the head of a lifting jack. On operating the jack, the incline H causes the housing to roll in the ball joint so as to lift the outer end of the lining above the button *l* on the axle, and then a slight lift of the jack relieves the rear end or heel of the lining or bearing, when it may be readily removed, and another substituted for it. The journal I is supplied with oil from the bottom of the housing by an endless wick J, which is carried on a rocking pad K, to which it is secured by the spring strap *m*. The pad K is held up to the journal by the vibrating frame L, in which it has a bearing *n*, and it is kept from being jolted off from this bearing by the spring *o*. The frame L is hung on trunnions *p p*, which rest in half-socket bearings *q q* formed in the sides of the housing, and are held in these bearings by the depending legs *r r* of the stopping bar M. The end of the frame L, which carries the pad K, is forced up by the downward pressure of the slide N on its opposite end. This spring slide N is attached to the stopping bar M by the bolt *s*, and is forced down by the spring *t*. Hinged to the frame L is a jumper or feeder O. This jumper has one or more teeth or hooks on one side of it, which catch into the wick J when the jumper is thrown up by the jolting of the truck, and by means of the weight of the jumper the wick J is pulled around. Not only is thus secured a plentiful supply of oil to the journal, but also the premature wearing out of the wick by the continual rubbing of the journal upon it at one point prevented. The stopping bar M is supplied with oil by means of an endless wick P, which passes around a tumbler or clack c' so hung in a slot in the bearing face of the stopping bar that it has a constant tendency to fall forward, and carry the wick against the end of the axle. Attached to the stopping bar by the bolt s is a jumper or feeder Q, having one or more teeth d', which catch into the wick P, when the jumper is thrown up by the jolting of the truck,

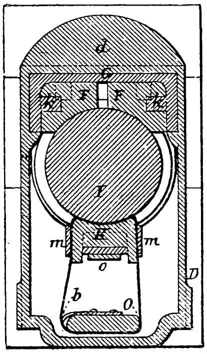
192.



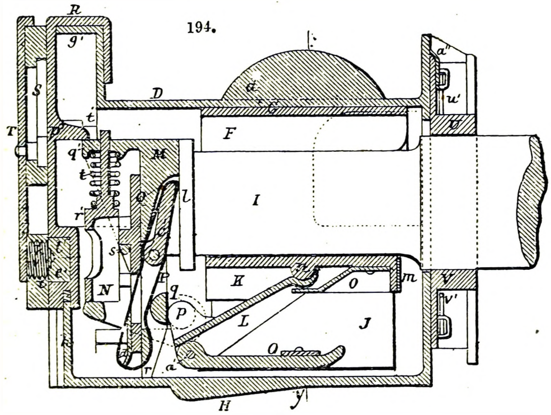
193.



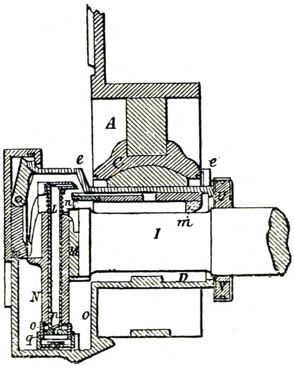
195.



194.



196.



and by means of the weight of the jumper draw the wick around. This ensures an adequate supply of oil to the end of the axle, and prevents the constant wearing of the wick in one place, which would occur if the wick should not be moved.

The opening at the outer end of the housing is closed by a sliding door R. When it is shut it is fastened by a spring bolt e', which shoots into a socket or recess in the side of the housing. Another socket is provided for the bolt to enter when the door is raised so as to keep it up. The door is packed to exclude the dust.

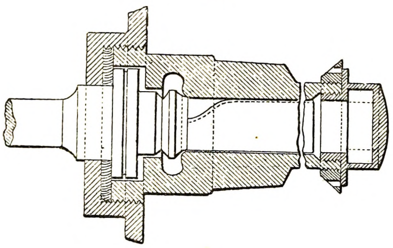
At the end of the housing where the axle enters it the opening around the axle is closed by two dust excluding plates U and V, which are halved together at the centre, and fit accurately around the axle. The edges of the plates in contact with the axle are enlarged so as to form a ring of considerable width and thickness. The plate U is held down and the plate V raised, so as to keep them both in contact with the axle by springs, which are fastened at one end to the plates and at the other are held in notches in the sides of the housing. A flat plate or spring, having its upper edge so bent as to lie closely against the housing and exclude the dust, is rivetted to the plate U.

In Fig. 196 the improvement is represented in its simplest form. By this construction the brackets are dispensed with. The momentum plunger L is tubular, to convey the oil raised by its vibrations to the height desired. This tubular plunger is placed in a vertical aperture or recess in the stopping bar M.

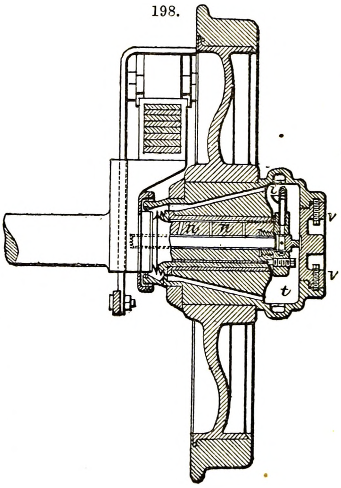
The plunger has sufficient weight to secure the necessary momentum, and to render its vibratory motions sensitive and effective it is partially or entirely supported by a spring. Its upward movement may be limited by its upper end striking the top of the housing, or by lugs or projections o, Fig. 196, from its sides, sliding in vertical grooves in the surrounding well or holder. The lower end or bottom of the plunger fits quite closely, but so as to move freely in a well or barrel N, which extends downward from the stopping bar or other support into the oil reservoir in the axle box. In the lower end of the plunger is a valve chamber, in which plays a valve of any suitable construction to allow the oil to enter the plunger from below and prevent its escape from the plunger. Thus whatever oil is once forced into the plunger by its sudden descent into the liquid below must be forced through the tube or passage of the plunger and discharged through a side pipe or spout near the upper end of the plunger.

For any ordinary axle, W. N. Morrell provides grooves which are made to run either diagonally or spirally from points from which the oil can be taken to the working parts of the axle, and a box or bush for the axle which, when the wheel is in motion, revolves on the axle, Fig. 197. The outside of the larger end of the box or bush is screwed, or has a thread cut to receive a washer or cap. The smaller end of the box or bush is also screwed, or has a thread cut to receive another washer or cap. The large screwed washer is placed on the axle behind the ordinary fast collar and the box or bush in the front of the fast collar and covering it. The washer is screwed on to the large end of the box or bush, packing being placed between it and the axle. By this means all the back lash caused by the wearing can be taken up; also in a case of breakage of the axle in the front of the collar the bush or box on which the wheel is placed is kept in position and cannot drop off. The screwed washer at the small end is made taper, and by it the nave of the wheel is kept tightly fixed on the bush or box.

197.



198.



199.

A. Osenbrück, of Hemelingen, Germany, overcomes the evil arising from the friction between railway car wheels and rails in passing round curves, and improves the means of lubricating the bearing or journal surfaces of such wheels and their axles by the arrangement Fig. 198. The axles are fast and the wheels revolve loosely on them.

Fig. 198 is a vertical section of a railway wheel and axle. The wheel boss is forced into the wheel by hydraulic pressure, a wrought-iron ring being then shrunk on. The nave is in front, surrounded by a concentric case, closed oil-tight by an end cover *v*, the space *t* between this case and the front part of the boss forms the oil-supply or centrifugal chamber. At the back or inner side of the wheel boss there is another concentric, but smaller, casing, closed oil-tight by a packing ring forming joint with the axle, the space within forming the oil-collecting chamber. The oil-supply chamber *t* and the oil-collecting chamber are united, by one or more passages slanting from the latter to the former. The collecting chamber is made sloping inside, increasing in diameter towards the opposite side of the wheel, and the slope of the connecting passages to the front or centrifugal chamber *t*, is made less than that of the oil-collecting chamber. The axle is formed with a central chamber, which may be filled with a filter or filtering appliance. The central chamber in the axle communicates by a passage with a catch tube fastened to the axle itself, or to a ring or disc screwed on to the axle. This tube reaches nearly to the greatest inside diameter of the supply chamber *t*, placed in a vertical position. Its mouth is splayed in both directions of revolution of the wheel, it has also a catch basin *i* beneath the mouth communicating with the interior of the tube. The central or filtering chamber is connected by several holes *n* with the journal to be lubricated.

To prevent the wheel from running off, a disc is screwed on the outer end of the axle, and a set screw put through it for greater security to prevent the disc from working loose. The disc has preferably a gun-metal facing where it works against the nave or its cast-steel bush. The oil is supplied to the oil-supply chamber *t* by taking off the front cover *v*. This cover then is closed oil-tight. From the inner side of the nave, oil escape is prevented by a leather ring fitted to the nave, and forming joint with the surface of the axle or with a collar. The axle has also a groove between the leather ring and the journal: the groove is flat or broad at the bottom, and with a sharp edge, the front side being vertical and the back sloping. Or, instead of a leather ring, a ring of lead, with a slight addition of antimony, may be cast on the axle, and formed with one or more grooves, the edge of the nave running on this hard lead ring.

The supply or centrifugal chamber *t*, has in its inner circumference receptacles in opposite directions. The object of these is to ensure lubrication even at the slowest speed, where the centrifugal power is not sufficient to distribute the oil all round the inside of the chamber *t*, and thus enable the tube *i* to catch it. The catch basin on the catch tube is a little wider than the receptacles, and of suitable length. When the railway wheel revolves slowly, all the eight receptacles are filled one after another when in their lowest position; four empty themselves again immediately, but the other four carry their oil up and empty it into the basin *i* of the catch tube, whence the oil flows into the tube and thence to the filtering chamber. The filter consists of a perforated tube surrounded by wire gauze and flannel. After it has been inserted into the central chamber in the axle the opening is closed oil-tight by a stop screw.

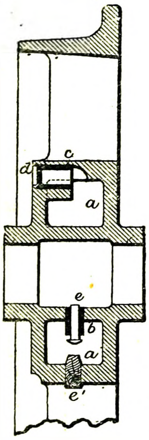
By these improvements there are sought to be attained a reduction of vibration, with its consequent molecular changes in the nature of the axle, whereby the metal becomes crystalline in its structure, a primary reduction of friction of the wearing surfaces in contact, a secondary reduction of such friction by the diminution of the vibration, and a consequent reduction in the wear and tear of rubbing surfaces. By the use of a soft metal bush in the nave the evil arises that this bush quickly wears larger in diameter than the bottom wearing surface of the axle, and the surface of contact between both is much reduced, and heat and undue friction and wear result. By the improvements described, the area of the wearing surface of nave and axle are little reduced, the wear being practically only in the nave. The proportion found most suitable is to make the width of the axle bottom wearing surface about three-fourths of the diameter, and to make the length of the journal about two and a quarter times the diameter at least. The wearing surface of the revolving nave is formed with a hard surface, for which purpose it is bushed with a cast-steel bush, or the nave cast on a chill, and afterwards, if required, ground true, the corresponding axle journal part is formed with a softer surface, for which purpose it is coated with gun metal, bronze, or other alloy. This soft metal coating is shrunk firmly on to the axle, and may further be prevented from turning or becoming loose by the set screw, preferably inserted endways in shaft and coating, and by a feather or key. Fig. 199 is a sectional view of the coating.

The journal of the axle is for about three-fourths of its length turned eccentrically, having its eccentricity towards the top, the remaining outer fourth part being concentric with the inner shoulder of the axle. The coating of the axle has a flange inside, working against the cast-steel bush of the nave, and has the greatest thickness below, where the wear is greatest, and its outer fourth part is a ring, but the remaining three-fourths have the greater portion of the upper half left out. The holes from the central or filter chamber terminate at the cavity or space thus formed, and a plentiful supply of oil is maintained here. The wearing surface at the bottom is only about one-fourth of the circumference, in order to save unnecessary friction.

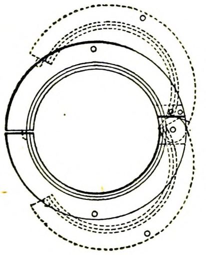
Fig. 200 is W. H. Llewellyn's wheel for colliery trams. This wheel is cast with an oil chamber *a* surrounding the nave or boss, the core from which chamber, after casting, is removed through openings cast in the side of the chamber, and which are subsequently filled up with closing pieces leaded securely in position. The arms and rim are cast together with the chamber *a*, into which the oil or lubricant is introduced through a hole *c*, under which is a trough-shaped space, in which is fitted an indiarubber thimble valve *d*, which is depressed by the oil can spout when filling the chamber *a* to allow of the oil entering, and which expands and closes the hole *c* upon the can being withdrawn, and prevents the oil escaping.

The lubricant or oil obtains access to the usual chamber, cast in the inner periphery of the boss and surrounding the shaft or axle, through one or more orifices *b* cast in the boss, and in which headed needles *e* work up and down by the travelling motion of the wheel, and prevent the thickening of the oil; this may also be effected by sponges, or by means of flannel or any woolly substance placed in the orifices *b*, and kept in position by tin clips. The needle *e* is inserted through a hole, which is afterwards closed by a hard plug of wood which regulates the travel of the needle.

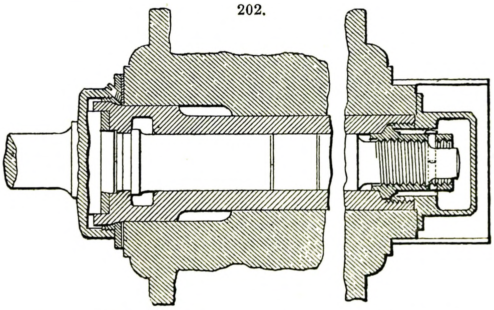
200.



201



202.

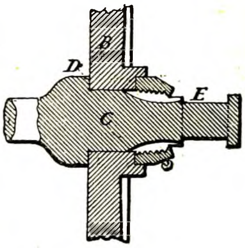


Figs. 201 and 202 are of E. Partridge's axles and axle boxes for wheels of road vehicles, the improvements being mainly applicable to those axles well known as old solid collar or Collinge's. The object is to secure wheels upon axles, that they cannot leave the vehicle in case of breakage or other cause. Fig. 201 is a view of a divided ring, formed by the two halves connected by an intermediate strip, so that the ring can be opened out to facilitate it being slipped into position after a wheel is upon the axle, but not full on as when ready for running. This ring, which may be solid or unbroken, has a screw thread cut upon its smaller exterior periphery to engage into a thread in the inner periphery of the solid or fixed collar of the axle to form the attachment of one to the other, the ring being held rigid against the frictional contact or action of the wheel by a screw stud. The face of the ring, from its larger periphery, abuts against the inner face of the hub or nave, while it rotates upon the axle, and serves in a measure to steady the wheel.

The internal periphery of the ring is tapered or inclined for about one half of its width, Fig. 202. This angled portion terminates in a horizontal part, which finds a lodgment or bearing against the horizontal part of the ring, so that the two surfaces, the angled and the horizontal, act in unison, and the wheel is prevented leaving the vehicle should the axle break from any cause outside the shoulder, where axles generally do break, consequent upon the length of leverage of the free end of the axle arm, the fixed point or fulcrum being at or near the inside of the shoulder. The horizontal part of the axle box is also sufficiently broad for its inner periphery to take a bearing upon the axle shoulder, and this serves or assists to serve to steady the wheel upon the axle, the box being kept up close to the leather or other packing washer by the ring.

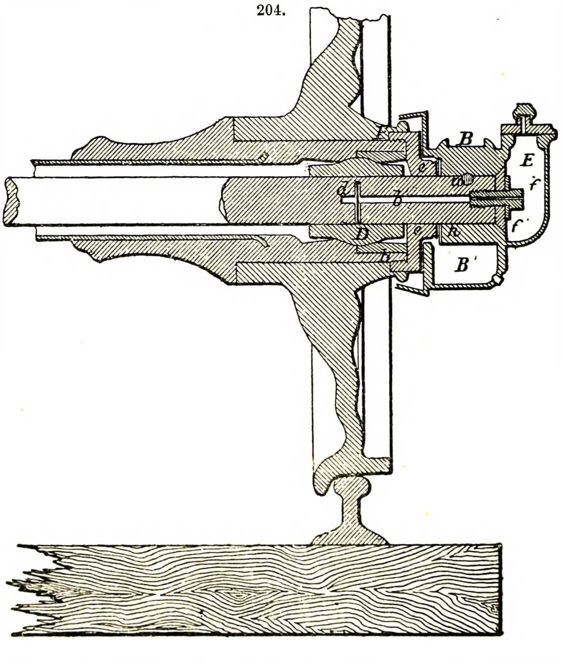
T. E. Dixon, of Chicago, has devised a means of furnishing a railway car axle, simply and cheaply constructed, which shall revolve as in the present system, but upon which the wheels are loosely mounted, to avoid the torsion, or twisting and slipping, occasioned by running on a curve or irregularity of the track.

203.



There is forged near each end of the axle a bearing larger than those at the ends, upon which the wheel is slipped till it strikes a shoulder raised around the inner end of the bearing, and is retained in place by a nut or cap screwed upon the axle till it strikes against the wheel. Thus constructed, when there is no irregularity in either the wheel or the track, the wheels will not turn on the axle, but wheels and axle will turn together on the smaller bearings at the ends in the oil boxes, in obedience to the mechanical law that a wheel free to move on either of two bearings, one larger than the other, will always turn upon the smaller bearing. When a curve or other irregularity is encountered, while the same motion of the axle is maintained, one or both of the wheels will turn on the axle just sufficiently to overcome the irregularity, instead of slipping on the track as when fastened rigidly to the axle. The advantages of having both the wheels loose is, that in turning a curve, while one of the wheels is pressed by the track so as to hug the axle tightly at the bearing, the other is left free to turn easily. The wheel is constructed with a hub projecting upon either or both sides, so as to give a larger bearing surface and better resistance to the effect of blows and concussions. The nut or cap extends from the wheel down near to the inner end of the outer bearing of the axle, and holes or grooves run diagonally through it or the axle from the oil box to the wheel. The oil escaping along the axle from the oil box is carried through these passages to the wheel. In Fig. 203, the axle has the usual outer bearing E, and an enlarged inner bearing C of double the diameter of the outer bearing, and of suitable length to fit the hub of the wheel. D is a rim or shoulder at the inner end of the inner bearing C, with an elevation of $\frac{1}{2}$ in. or $\frac{3}{4}$ in. B is the wheel turning freely upon the bearing C, and held in place by a nut or cap, which is screwed upon the axle, and prevented from turning by a screw or bolt passing through its sides into the axle. If preferred, the ends of the hub of the wheel may be grooved out, so as to fit over either or both the shoulder D and the nut or cap. The elevated shoulder D, and also the bearing C, are of greater diameter than the body of the axle, thus, with the least weight of iron, giving the greatest strength to the axle at the point where fracture usually takes place, and the better enabling it to resist the effect of blows and concussions coming through the wheel.

204.

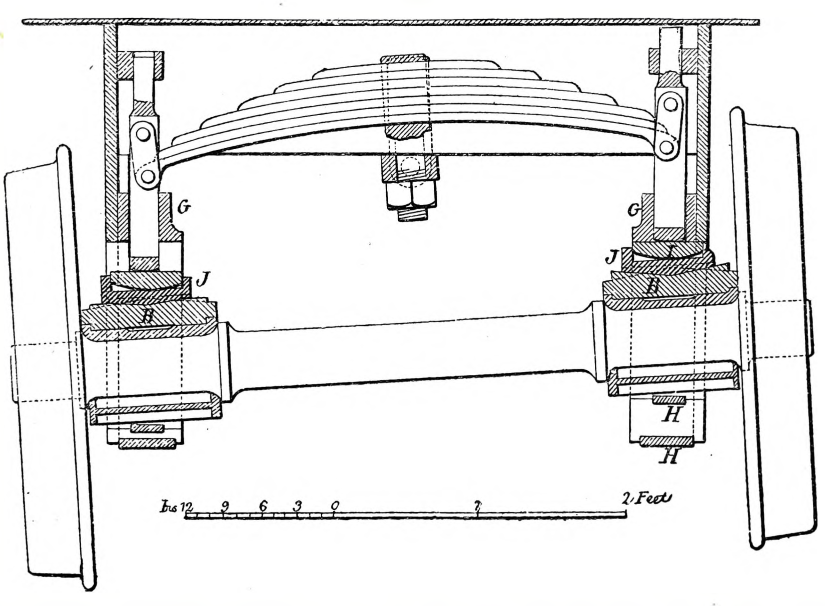


G. W. Miltimore, of Wisconsin, has effected improvements in that class of railway-carriage axles, in which a stationary inner and a revolving outer wheel carrying axle or sleeve are so employed, that the lubrication of the journal box from the oil reservoir is accomplished to the exclusion of dust, the drip oil collected. The journal box is allowed to oscillate in the stationary axle to conform itself to a true bearing throughout according to the spring of the axle produced by the weight of the carriage. An air-tight oil reservoir on the pedestal box is connected by a longitudinal and vertical channel and vibrating feed pin in the stationary axle with the revolving journal box. An oil-tight joint between the pedestal box and stationary axle is formed by a cork disc, washer, and hollow screw plug. The lateral motion is taken up between the nut and the stationary pedestal block. The rotating journal box bears by a central annular convex part and slightly inclined ends on the correspondingly shaped outer sleeve and ring to provide for oscillating motion. The surplus oil is collected in a drip chamber by means of an annular rim or bead of the closing nut of the outer axle. The outer axle or sleeve is made of cast and wrought-iron sections combined. Fig. 204 represents a central vertical section of this railway carriage axle, in which the stationary axle is rigidly connected with the spring or pedestal bearers B, by horizontal locking pins *a*. The revolving outer axle or sleeve is made of a laterally connecting wrought-iron section with end lips and wheel carrying sections cast on. The journal box D revolves with the sleeve on the stationary axle, and is lubricated from an air-tight oil reservoir E, of the pedestal box, the reservoir being connected with the journal box by a horizontal channel *b*, and a vertical channel in the stationary axle. The vertical channel extends above the horizontal channel, and feeds the oil by a vibrating spring pin to the journal. The contact of the feeder pin with the revolving journal box during the motion of the carriage keeps the pin continually in motion, and admits small quantities of air into the channels, and to the oil receptacle. The vibratory motion of the feeder pin furnishes mechanically a small air supply to the oil receptacle, and allows the feeding of a corresponding quantity of oil, which increases or decreases in proportion to the speed. When the carriage is at rest the oil ducts or channels are filled with the oil, but the air supply is discontinued, as the feeder pin is also in a position of rest, and supplies no air, so that the oil is held suspended by the partial vacuum in the oil receptacle and prevented from running out. The surplus oil of the journal box passes out through a closing nut or cap F, screwed to the sleeve and encircling the axle. An annular rim or bead of the cap F conveys the drip oil into a chamber or receptacle B^1 of the pedestal box below the axle, from whence it may be drawn off by a screw plug. An oil-tight joint is formed between the pedestal box and stationary axle by a tapering cork disc and washer *f′*, and perforated screw plug *f*, preventing the oil from passing in or out between the pedestal box and axle. A loose steel collar or ring *h* is placed on the stationary axle between the pedestal box and the revolving screw cap of the outer axle, to provide for the wear caused by the lateral motion of the carriage which is taken up between the pedestal block and screw cap at that point. The journal box D is made with a central convex part, and slightly tapering end. The outer axle or sleeve rests on it by a corresponding annular concavity, and an outer ring. The sleeve and ring are arranged adjoining to the annular concave parts, with slight outwardly inclined parts, which form, with the tapering ends of the journal box, narrow annular spaces that provide for the oscillating motion of the journal box, when the weight of the carriage causes the springing of the inner axle. The journal box is always in full contact throughout its entire length with the inner axle, and compelled to wear out evenly.

Figs. 205 to 216 show a form of radial axle box designed by H. W. Widmark, of Bristol, and described by him to the Institution of Mechanical Engineers in 1877. These axle boxes are made with the curvilinear sides and girders, common to English practice, which allow of both lateral and radial motion of the axle, but obviates certain difficulties of construction and use.

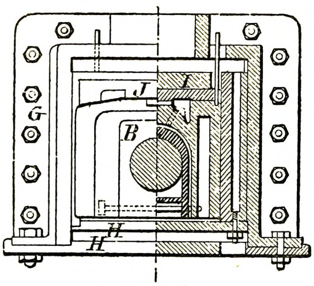
Each pair of girders G G, always cast in one piece, whether fixed to the main frames of the engine, as in Figs. 205 to 208, or to cross frames, as in Figs. 209 to 211, is distinct from the other, and is bored to a cylindrical surface, the axis of which is in the same line as the spring. An intermediate guide or box I I, the outer surface of which is turned so as to fit easily into the outer guide, can have a turning motion round its axis, and also an up and down motion, as may be required by the elasticity of the springs or the roughness of the road. The sides of the inclined passage through this piece are planed, and serve as a guide for the axle box proper to work in. Both the outer and the inner guides have their lower forks connected by horned stays H H to prevent springing.

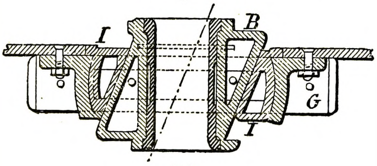
205.



The axle box B has planed parallel sides, and is free to slide in a direction which is rectilinear and horizontal, but inclined to the axle of the wheels. The box at the opposite end of the axle is inclined in the opposite direction, as in Figs. 208 to 211; so that when the wheels and axles deviate towards one side in consequence of the curvature of the road, the axle is simultaneously set in an oblique position to the engine frame, but radial to the road, one end being advanced in relation to the frame, while the other is drawn back by the inclined form of the axle boxes and the intermediate guides. Moreover, as the sides of the axle boxes are parallel planes, and as there are no flanges, the axle boxes are free to turn round a horizontal axis which is at right angles to these side planes. Thus one axle box may rise and the other fall in the guides, as required by the state of the road. This very necessary motion is prevented when the sides of the boxes form parts of circles, fitting to corresponding curvilinear surfaces on the guides; such boxes move freely only when they both stand the same height in the guides, but would be in danger of jamming and fixing the axle if the oscillation of the engine, or the irregularity of the road, made one box rise more than the other.

206.





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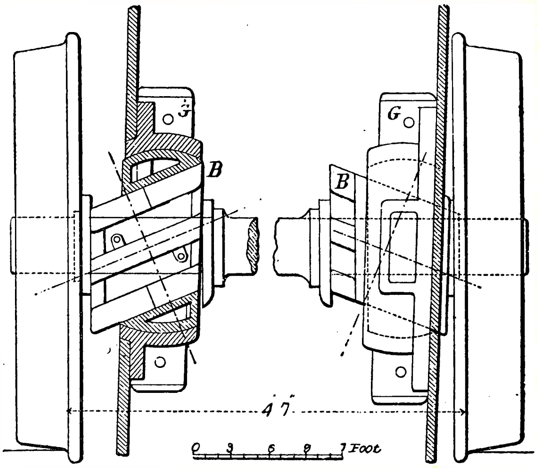

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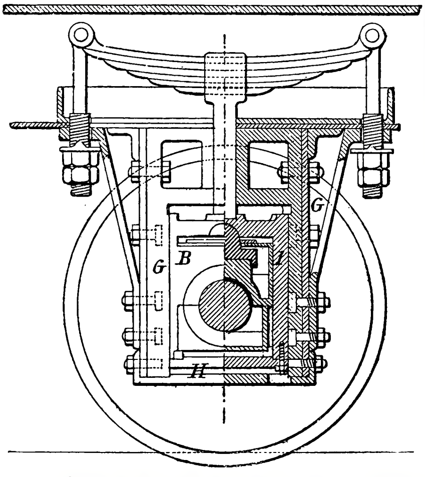

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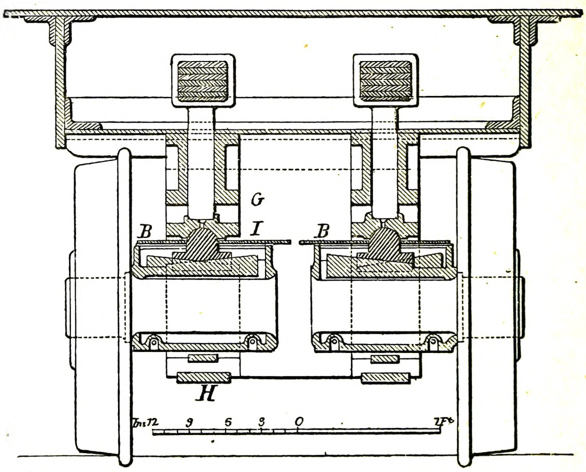

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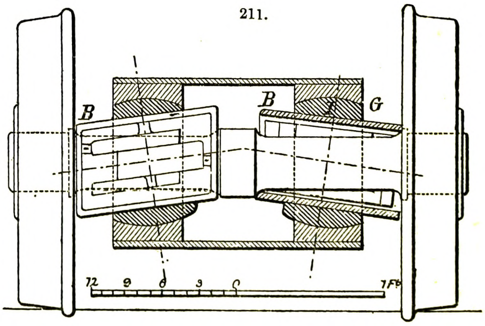
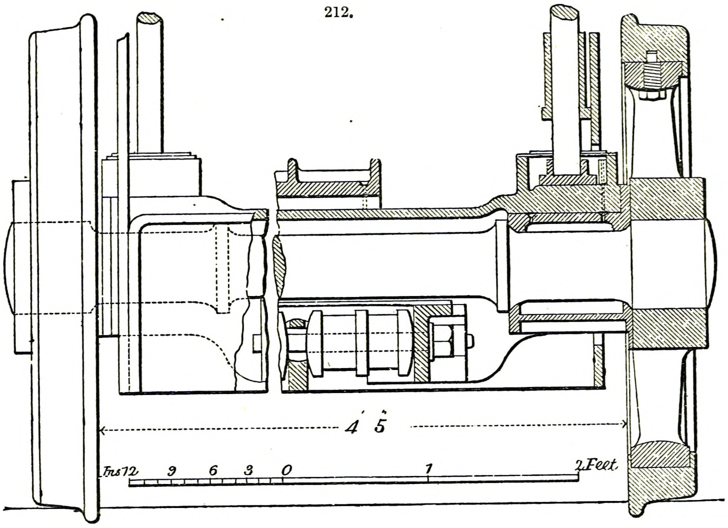


In Fig. 205 is seen a frame with its guides in such an inclined relation to the wheels, axles, and radial axle boxes. In Widmark's design each axle box system becomes a universal joint, for there is a vertical turning of the inside guide in the outer guide, a horizontal turning of the axle box in the inner guide, and also the turning of the axle box round the axle. There is, thus, no possibility of the axle becoming jammed in the guides.

As in this design the axle box travels in a direction which is rectilinear, it is easy to arrange inclined planes on the top of the box, and corresponding inclined planes on a sliding piece J, Fig. 205, which is held by the inner guide, and takes the thrust of the spring. By this means an elasticity is given to the axle, or a tendency to come back to a central position when not constrained by the curvature of the line. On a straight line, the axle is locked by the inclined planes just referred to, so that it becomes parallel with the other axles, whereby friction is prevented between the wheels and rails; in this way the engine is also steadied, the swinging action of the cylinders being prevented. One system of six inclined planes is shown in Figs. 205 and 208, and another system with but three planes in Figs. 210 and 211. In the first, the inclined planes are entirely above the box, Fig. 205, and are lubricated by separate oil pipes and grooves; in the latter the inclines are placed over the box, Fig. 210, but at a lower level, so as to be surrounded by the upper flanges of the box, and are always immersed in a bath of oil, which is covered in and guarded from dust by fixed and sliding covers.

212.



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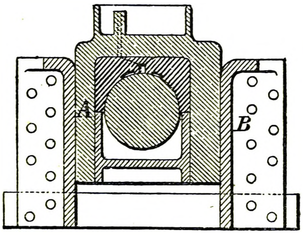

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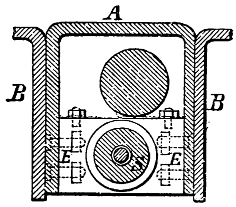

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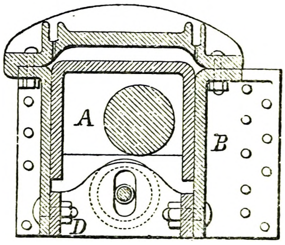

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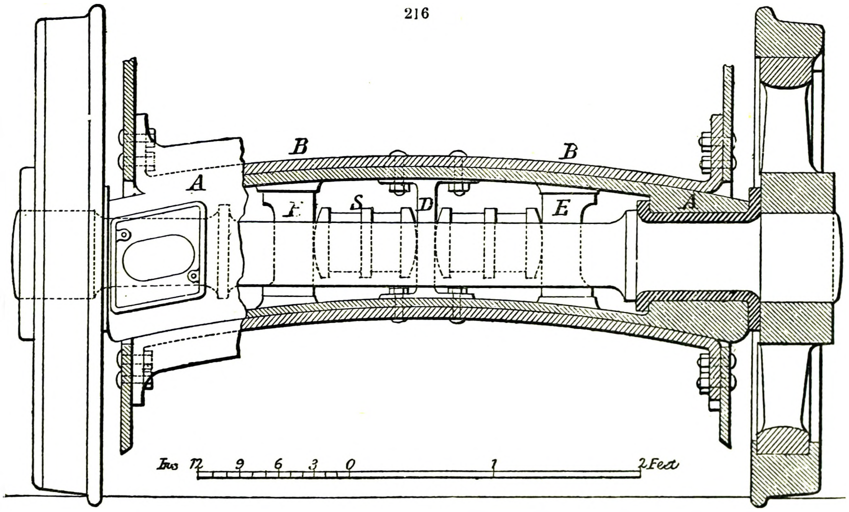
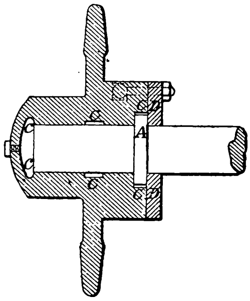


In the case, Fig. 216, instead of the two ordinary independent axle boxes for the leading wheels, one on each side of the engine, there is only a single long axle box, in the form of a plain cast-iron girder A A extending from side to side, and forming in plan a circular arc struck from a point half-way between the driving and trailing axles. Two corresponding curved wrought-iron plates B B, bolted to the engine main frames, encase the curved axle box at front and back, without any fitting, the space between the two plates B B being about $\frac{1}{8}$ in. wider than the girder A A, which works between them. No fitting is required, and the axle box and plates have little wear, as a trifling slackness is of no consequence, for when the engine is running forwards the axle box presses against the front plate, and when backwards against the other plate. An ordinary brass bearing is fitted to each end of A; and a spring pillar bears upon a plain footstep C, sliding upon a flat surface in the grease box or top of the axle box. The axle box being a rigid girder from end to end, the pressure upon the journals is not affected by the spring pillars sliding laterally with the engine frame, but is very much the same in any position in which the engine may be on a curve. The difficulty of lateral oscillation is counteracted by putting side controlling springs.

There is a centre stay across at D, this ties the front plate to that behind; and on each side there is a stay across the axle box at E E, a bolt passing through the three stays, the hole in the middle one is sufficiently large to allow of the play of the axle box. The bolt carries a pair of indiarubber buffing springs S S on each side of the centre stay, and these are regulated so that about half a ton lateral pressure against the wheel flange is sufficient to throw the engine over towards either side to the full extent of the lateral movement allowed.

Fig. 217 is of a practical method of fastening colliery tram wheels to the axle and means of lubrication. C C C are oil chambers, D D wrought-iron loose collar, S set screw closing inlet hole for oil, A wrought-iron collar welded on shaft.

217.



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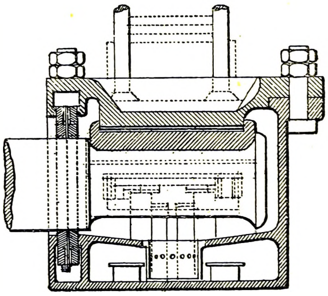

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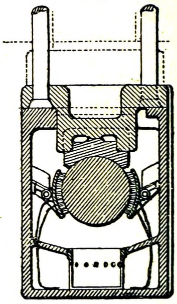

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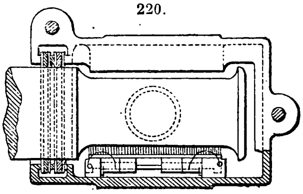

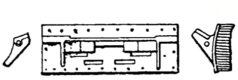

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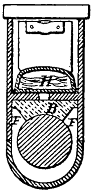
222.



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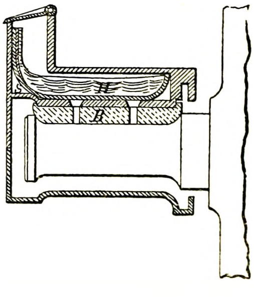

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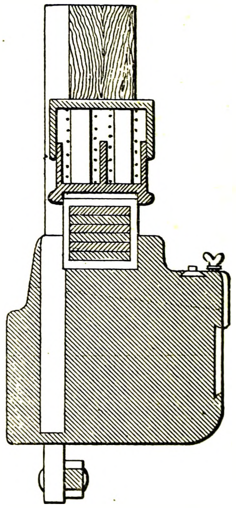


Figs 218 to 221 are of an oil axle box designed by E. Beuther, and largely employed on the Bergisch-Maerkische Railway and other continental lines. The main features are the drawing up of the oil by capillary attraction from below to cotton pads, so hinged against the journal as freely to adjust themselves to it by gravity. The spent oil is led into a central reservoir below, where it can deposit its abraded metal and grit. A cast-iron cover is fitted to the box, which is cast with lugs to receive the hinges of the brass padholders. From four slits in the back of each holder there hang down as many siphon wicks, dipping into the main reservoir below. Any excess of spent oil drops from the axle into the central wrought-iron cup, which communicates with the main reservoir by holes at its upper end, so that it forms a separation of any impurities. The joint between the axle and the box is made by two separate slips of wood, fitting tightly on the axle, and made to bear vertically against each other by means of a small spring below, so that all wear in the only directions, above and below, in which it can occur, is taken up. In a trial made to compare the economy of these boxes with those in general use, it was found that 33,943 miles were run with the consumption of three-quarters of a pint of oil, while the ordinary box used $3\frac{3}{8}$ pints.

Blackburn's oil lubricator for grease boxes, Figs. 222 and 223, consists of a flexible oil holder H filling all the grease compartments. It is formed of a bag made of oil-cloth. This bag is contained within another of felt. From the mouth, kept open by a coil of wire, there hangs down a capillary feeder, to which, when the carriage is in motion, the oil is shaken up, making its way up this feeder to the enclosing felt bag, which acts as the long leg of a siphon H, and the capillary feeder as the short leg. The brass bearing B is fitted with wooden fillets F for evenly spreading the oil, or a pair of long strips of felt may also be let into the substance of the brass. The attachment of the fillets in the first case, or the slots cast into the brass in the second, form the only alterations required. These fillets are simply fixed by pins driven into a pair of small holes drilled into the edges of the brass. The flow from the reservoir only takes place when the oil, by the motion of the carriage, is splashed up against the hanging wick or shorter leg of the siphon. Waste is thus prevented when the carriages are standing. Another plan consists in placing a long felt pad inside the bottom of the box, and kept up against the neck of the axle by a spring. The whole is slipped into the box through a hole tapped for a screw, which then closes up the box; the motion of the carriage and the capillary attraction of the felt keep up the supply. An objection to the first plan is the facility given by the flexible and removable oil vessel for pilfering the oil. This objection might be met by applying some adhesive composition to the sides, preventing removal without loss of time in the destruction of the vessel, which costs only a few pence.

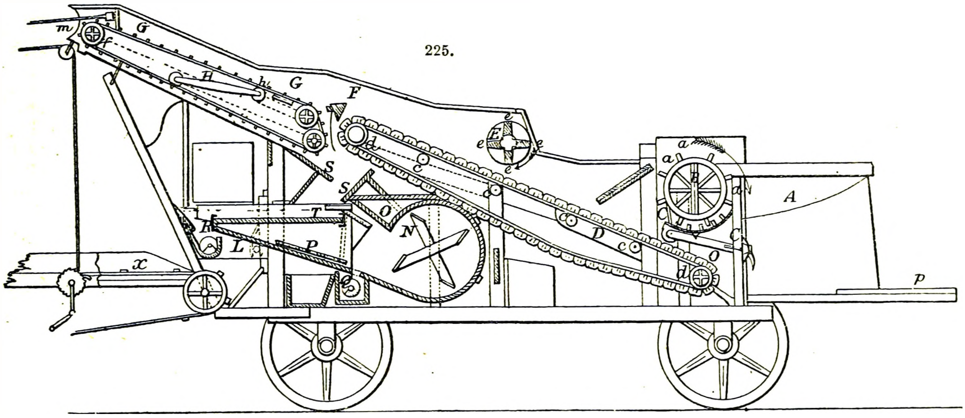
Fig. 223 is of Thomson's compressed wool and steel cushioned springs. These consist of a coiled steel spring, the central portion of which is filled in with wool highly compressed. By this means the effects of concussion are reduced.

BARN MACHINERY.

Under this head is included some of those machines necessary to agricultural purposes in, or in proximity to, the barn where the crop or produce of the land is usually treated.

Threshing Machines.—A good example of an American threshing Machine is that made by the Pitts Works, Buffalo, New York, of which Fig. 225 is a section. Here A is the feed-board, B the drum, C concave, D grain-belt, *c d* ends of supporting rollers, E beater, F picker, G straw-belt, N fan, O fan-case, P fine sieve, Q grain conveyor, R tailings conveyor, S guide-boards, T sieve, *m* opening for straw, L eccentric, *x* straw-elevator.

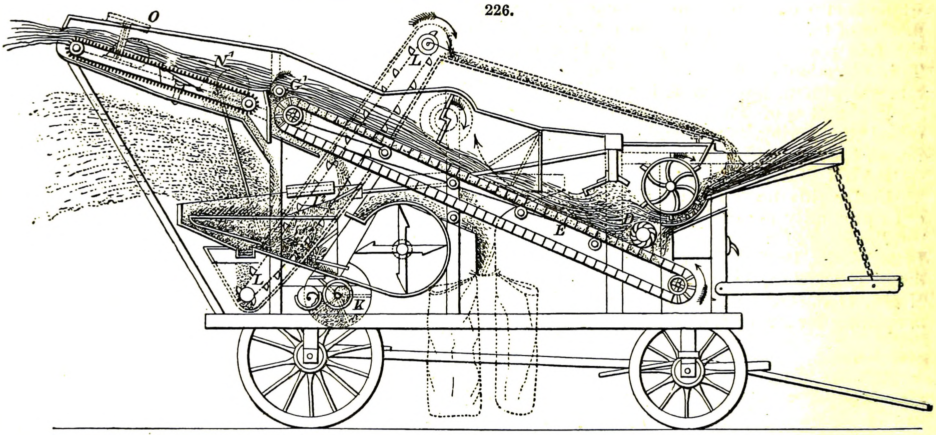
225.



The workman who acts as feeder stands upon the platform *p*, and spreads out the corn upon the feed-board A, presenting the heads to the action of the pegs on the drum. The drum-axle is a solid shaft 1⅞ in. diameter. The drum is 36 in. long with nine longitudinal bars, holding 104 teeth, which project 2½ in. from the face of the bars. The concave is made in three parts, with an adjusting screw. The teeth on the drum, as they revolve, pass close to similar teeth in the concave. Such portions of the grain as are not separated by the blows from the teeth on the first contact, are drawn with great force past the concave teeth, and thus the heads are combed out. Nevertheless, portions altogether escape, as is shown by the delivery from the return spout. The drum revolves from 1000 to 1300 times a minute. The drum pulley is 7 in. in diameter with 8½-inch face. The grain and straw fall together on to the grain-belt D, an endless belt about 10 ft. long, composed of stout duck, on which are nailed buckets of maple, 1½ in. wide, with intervals of 1¼ in. The grain drops into these intervals and the straw rides on the top, its progress being expedited by the action of the beater E, an iron shaft with four arms furnished with fingers *e*, driven from the opposite side of the drum-shaft, and making about 400 revolutions a minute. This is an important feature, preventing the clogging of the machine, which would otherwise frequently happen in the case of damp straw. The supporting rollers *c c* being hexagonal, give a jerky motion to the grain-belt, which separates any loose grains lodged in the straw. The triangular revolving picker F, placed just above the end of the belt and between it and the straw-carrier, prevents the straw passing downwards with the grain, and assists its passage forward on to the straw-belt G, made of slats of wood nailed at short distances from each other to two leather belts, and forming an endless ladder running over the pulleys. The agitator, a bar rocking on its centre, so that the ends shake the straw-belt alternately, gives it a jerky motion which effectually causes the separation of any loose grains that may have hitherto escaped separation, and which now fall through the open spaces of the straw, or to the inclined board, whence they find their way to the shoe. The chaff is separated from the grain by the action of the fan N; the grain falls through the screen T, on to the fine sieve P, which forms part of the bottom of the shoe. Weed-seeds and the like escape into a box, whilst the grain drops into the grain conveyor Q, a trough with a revolving screw, and is discharged at the side. The cavings, which include the unthreshed or partially threshed ears, pass over the end of the screen T, fall into the conveyor-box R, and are delivered by a similar screw to the elevators, by which they are carried back to the drum and rethreshed. A longitudinal motion is given to the riddle by means of the eccentric L. A light straw elevator is attachable to the end of the machine, a portion of which with the side frame removed is shown at x, this can be fixed at any angle by a rope wound round a pulley, with a ratchet wheel and pawl to secure its position.

Fig. 226 is a section of a machine of somewhat similar construction, made by John Abell, Ontario, which has some original features. The revolving grate D, a small wheel furnished with a series of sharp sections, is for assisting the passages of the grain from the drum, and at the same time acting as a rubber to separate whitecoats. This latter office is only, however, very imperfectly performed; and the chief advantage of the grate is that it forms a convenient medium for transporting the grain from the drum to the buckets of the carrier. The latter is, both as to length and construction, very similar to the same apparatus in the Pitts Machine, only the friction-pulleys that support the carrier are round instead of hexagonal; there is also a slight difference in the form of the beaters and pickers. The picker G^1 makes about 1400 revolutions a minute, materially assisting the transfer of the straw on to the rakes, which travel at about half that pace and get a jerky motion from the blows of the agitator N^1; after the chaff has been blown away by the fan, the grain reaches the compartment K, the base of the grain conveyor; here it is partially rubbed by the arms of a small fan, which forces it upwards along a small elevator tube by which it is conducted to the sack's mouth, the outlet being here sufficiently high to allow of a sack standing upright under it. The cavings fall over the end of the shoe to the base of the elevator L, by which they are conveyed back to the drum; by a clever arrangement of an angle pulley, shown by dotted lines at O, and chain gearing, the straw-elevator can be fixed at any angle, so as to convey the straw from the machine in any direction from a straight line to a right angle. As far as the winnowing process is concerned, this machine is similar to the single-blower English machine.

226.



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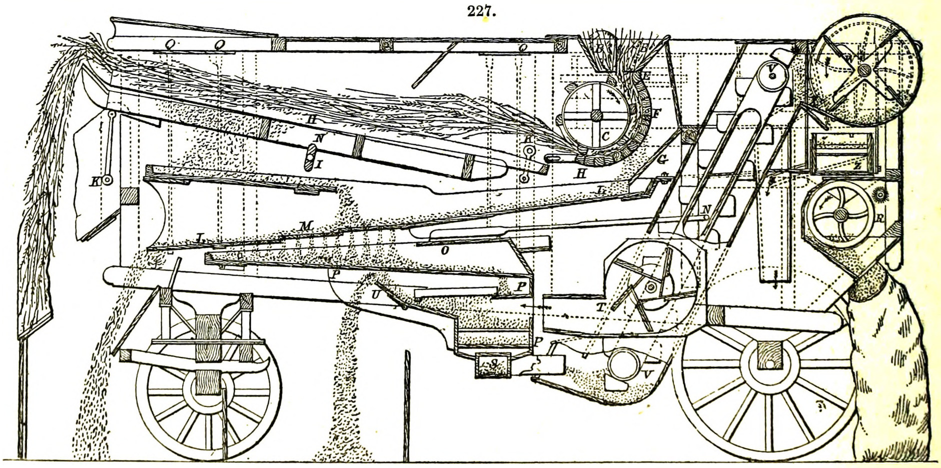
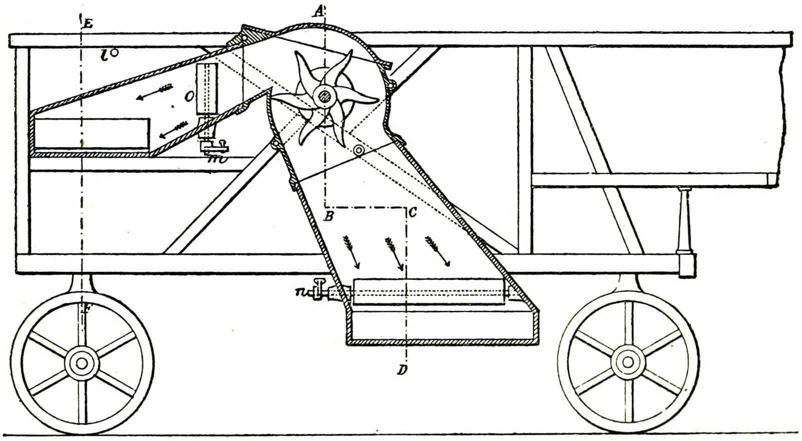


Wallis and Steevens, of Basingstoke, have introduced a threshing machine, Fig. 227, in which A is the feed mouth through which the unthrashed corn is fed into the machine. B B are adjustable mouthpieces for increasing or decreasing the size of the mouth to suit different descriptions of corn. C is the threshing drum, which has a steel spindle, wrought-iron head and rings, and either six or eight beaters of ash wood, fitted with beater faces and plate-iron fronts. D, a concave breasting, is made entirely of wrought iron and provided with adjusting screws E, and the hinge F for regulating its distance from the drum. G, casing behind concave breasting which carries the threshed corn as it passes through the bars of the breasting on to the upper shoe on the riddle-board L. H are the straw-shakers worked by the shaker-crank I, each alternate shaker being attached at either end to links J, turning on centres K. The shaker removes from the threshed straw any loose corn which may be left in it. L is the vibrating shoe on which the corn falls from the drum and shakers. In this shoe is fixed the perforated mahogany riddle M, which separates the short, broken straws, technically termed cavings, from the corn. This and the lower shoe is driven by connecting rods from the riddle-crank N. O is the lower vibrating shoe, to which is fixed the first winnowing machine P. Both shoes are suspended from the framing of the machine on spring hangers Q. P is the first winnowing machine, in which are placed an upper perforated zinc riddle, which assists the blast in separating the chaff from the corn, and a lower riddle for removing husks containing grains of corn. Beneath these is the spout S for conveying the corn to the elevators. In the bottom of this spout is a third riddle, not shown, for separating small seeds which may be mixed with the corn. T is the fan which supplies the blast of air to the winnowing machine P. Slides are provided to the openings in the centre of the fan through which the air is drawn in, and by these the strength of the blast can be regulated to suit the grain to be threshed. By raising or lowering the hinged flaps U at the back of the winnowing machine the whole of the chaff can be blown over without carrying corn with it. V is the elevator which carries the corn up and delivers it either into the barley-horner W, or direct into the second winnowing machine. W is the barley-horner, the steel blades of which are set at an angle so as to throw the corn out at the upper side of the horner-casing. By raising the hinge-valve X, by means of a handle outside the machine, the corn will then fall on the slope board Y instead of on the valve, and so pass direct into the second winnowing machine. This arrangement is of importance, as some kinds of grain and beans and peas would be injured by being passed through the horner. Z, the second winnowing machine, which has a set of hard wood riddles for thoroughly separating from the grain any chaff, chobs, &c., which may have passed the first winnowing machine, or have been rubbed off in the passage through the horner. It is suspended on spring hangers and vibrated by a connecting rod fixed to the end of the upper vibrating shoe L. A blast of air is blown through the winnowing machine by a fan fixed outside the framing of the machine, shown by the dotted line behind the barley-horner. R is a Penney's rotary screen, which separates the clean corn into three samples—best corn, best tail, and small tail. A brush keeps the rotary screen clean.

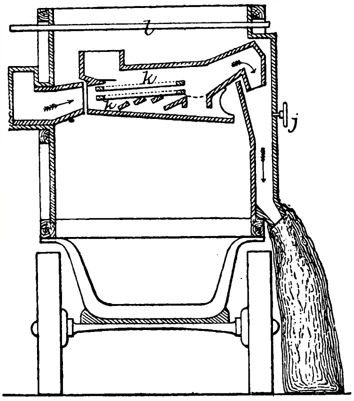
R. Garrett and Son's threshing machine, Figs. 228 to 230, has the following principal features. The blast sufficient for three dressings is provided by a single fan. This fan is attached to the drum-shafts, obviating the use of three separate fans with the accessory gearing, and consequent loss of power. The general arrangement is apparent upon inspection. A, Fig. 228, is the blast case, *o* the regulating valve with its lever *m*, *l* is the spindle of the aviller or chobber, *n* is the lower valve lever. Fig. 229 is a section on the line E F, in which *k k* are the sieves, and *j* the regulating hand-wheel. Fig. 230 is a section through A B C D of Fig. 228, *h* is the drum, *g* the lower screen, and *i i* the sieves.

228.



Feeding Gears and Drum Guards.—Figs. 231 and 232 are of Ruston and Proctor's feeding gear for threshing machines. *a* is a hopper or box containing spindles which carry a number of curved tines *c*. These tines are revolved in the direction shown by the arrows, by means of toothed pinions, motion being given from the shaker crank-shaft to a pulley *p* upon the end spindle. *e* is a wrought-iron plate, curved so as to deflect or turn the corn into the drum, and has a number of notches in its upper edge for the tines upon the end spindle to pass, which prevents any of the corn being returned over the spindles. *f* is the drum, *g* is the concave or breasting. The shakers to carry off the corn are not shown. The sheaves of corn are placed in the hopper at *a*. The bands having been cut and the sheaf just loosened, it is received immediately upon the first set of tines and delivered into the breasting *g*, where it is threshed in the usual manner, the straw being carried away on the shakers. By this system no loose grains of corn can pass to the shakers unthreshed.

229.



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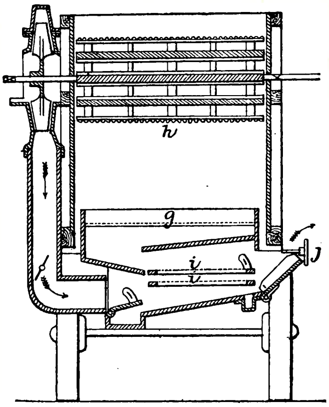

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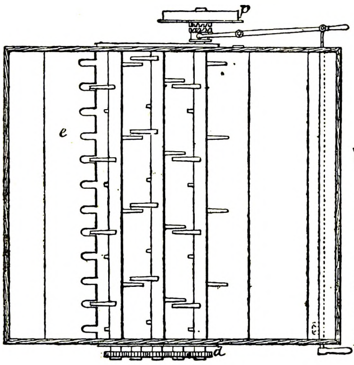

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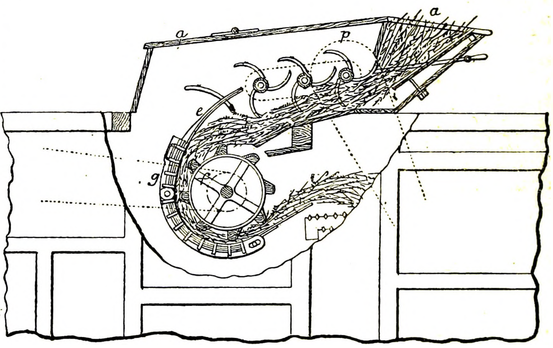
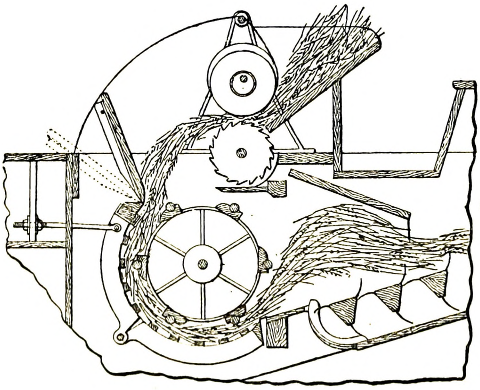


Figs. 233 and 234 are of Head's self-feeder for threshing machines, which serves also as a guard for the drum. It is a combination of rollers placed in the vertical mouth of a hood. One is a six-sided or corrugated wooden roller, and is run at rather high speed by a strap. Above it and parallel runs a fixed shaft, on which are loosely strung a number of heavy wooden discs about 10 in. diameter, covered with leather. A man could not get his hand drawn in between the rollers, because when an obstacle interposes the disc rises and ceases to revolve. Figs. 235, 236, and 237 are of Clayton and Shuttleworth's drum-guard. It consists of a combination of hood and feed-board, so that pressure being applied to either, both close simultaneously, covering the mouth of the drum. An

233.



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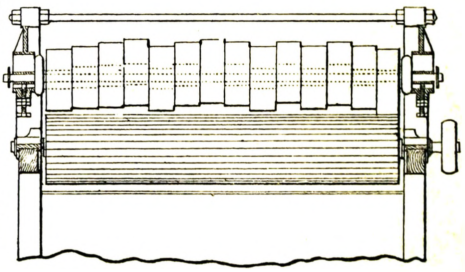
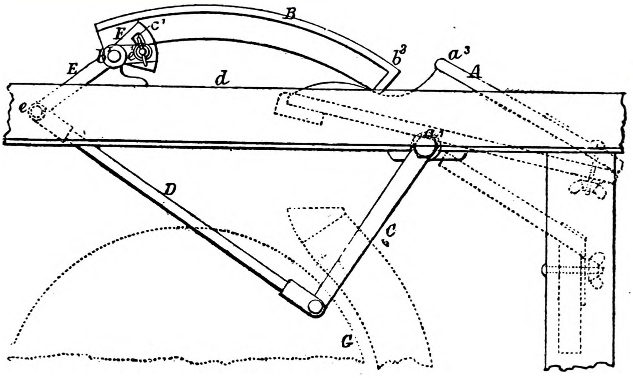


adjustable balance feed-board A extends across the machine and carries pivots $a\ a'$ mounted in bearings at a^2 in the frame A′. This is combined with a hood B, carrying pivots $b\ b'$, which are supported in bearings, the feed-board A and hood B being connected so as to admit of their working in unison in the following manner. To the end of the pivot a' of the feed-board A is secured a lever C, which is connected by a coupling rod D to one arm e of a double-armed lever E, mounted loosely on a pivot b', and carrying on its opposite arm e' a pin having a thumbscrew c. The latter

235.



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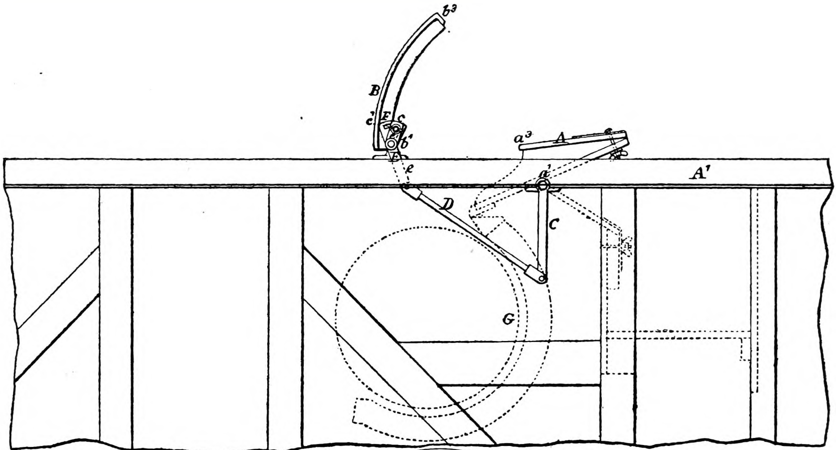
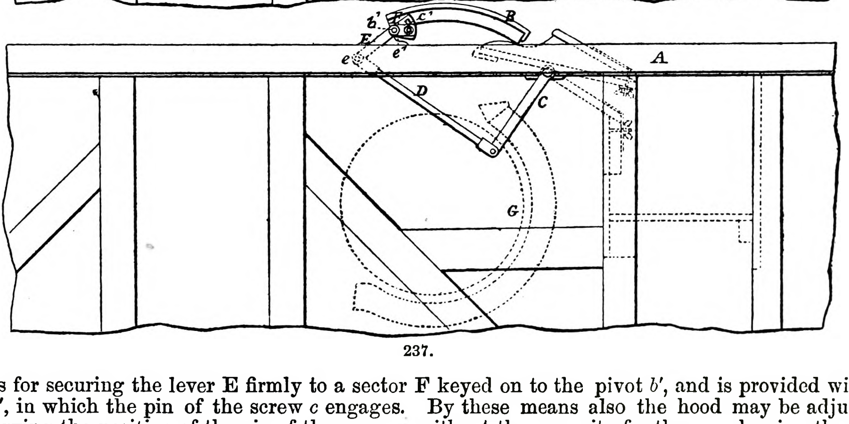




237.

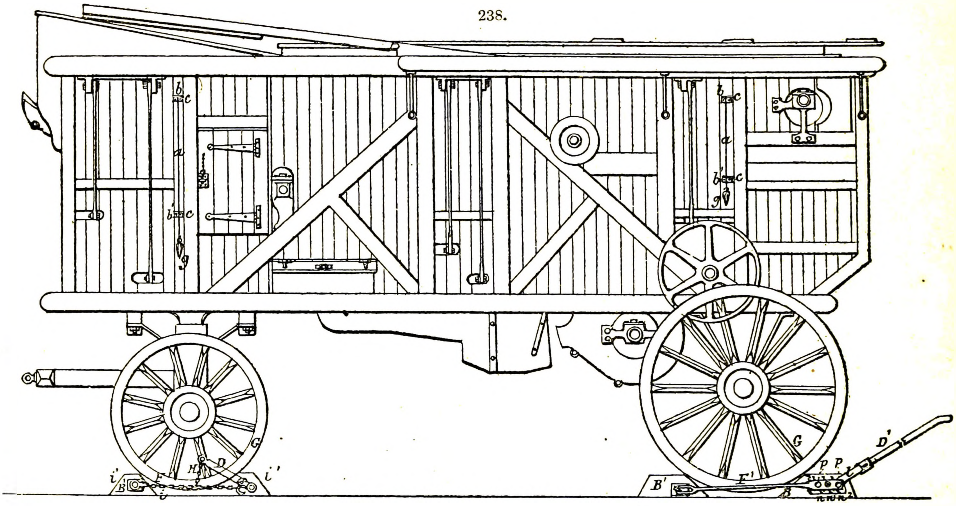
serves for securing the lever E firmly to a sector F keyed on to the pivot b', and is provided with a slot c', in which the pin of the screw c engages. By these means also the hood may be adjusted by varying the position of the pin of the screw c without the necessity for the man leaving the box. The hood and feed-board are represented closed in Figs. 235 and 237, and in their normal position in Fig. 236.

Chocking Blocks.—The simple and effective appliances of Clayton and Shuttleworth, of Lincoln, for adjusting the position of portable machinery and for chocking the travelling wheels, are shown in Figs. 238 to 242.

These means of adjusting the position of portable machinery during work consist in the arrangement at each end of the machine of a plumb line *a*, Fig. 238, by two small angle brackets *b b*¹, provided with vertical flanges *c c* for attachment to the frame.

The bracket *b* near the top of the frame has a small hole, tapering narrower downwards, drilled in it for receiving the knotted end of the plumb line *a*. The lower bracket *b*¹ is attached near the bottom of the frame, and has a similar hole, larger than the one in the upper bracket, but concentric with it, so that a line drawn through the centres of the two holes will be parallel both with the upright of the frame and the side boarding. The cord *a* is left sufficiently long for the bob *g* to be placed at rest in a hole cast in the lower bracket *b*¹ whenever the machine is travelling.

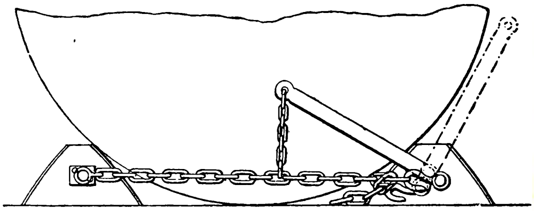
238.

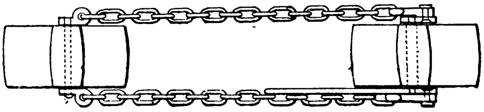


For levelling up the travelling wheels when standing on uneven ground, a pair of wooden chocks or wedges are placed under the tire of the wheel which requires raising, and these wedges are drawn towards each other by suitably arranged hand-levers.

In the mode illustrated in Figs. 239 and 240, and on the left-hand side of Fig. 238, a shaft is employed moving in bearings in the wedge B, and having a crank at each end, and a lever D formed in one with the corresponding crank, and projecting in a direction opposite to it. The cranks are attached by hooks, which they carry, to two chains F F, affixed one at each side of the opposite wedge B¹. When the hooks are to be attached to the chains the lever D is placed in the position indicated by dotted lines in Fig. 239, and the hooks having been each caused to engage with a link of its corresponding chain F, the lever D is pulled towards the opposite chock B¹, the cranks thus draw on the chains F F, and cause the chocks B B¹ to approach one another, thereby raising the wheel G which is placed between them. On the lever being returned to its original position, shown by the dotted lines, the chains F F slacken, when a fresh link may be placed on the hooks of the cranks, and another pull given to the lever D. This process is continued until the plumb line on the machine coincides with the centre of the slot of the lower bracket, when the lever D is secured in position by means of a short chain H and hook at its end, which is inserted in a link of one of the side chains. The chocks are reversible as shown, with their two ends *i i*¹ of similar form, so that when the end *i* is worn the other end *i*¹ may be brought into use.

239.





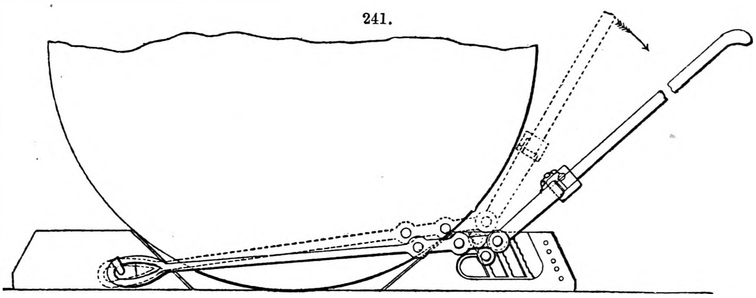
240.

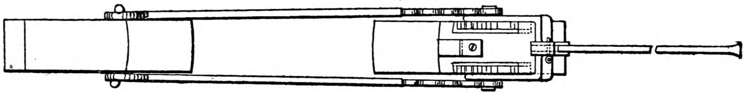
A modification of this is shown in Figs. 241 and 242, and on the right-hand side of Fig. 238. Here a loose forked lever D¹ is employed, having a fulcrum-pin projecting inwards from the end of each branch *l* of the fork, and another pin with enlarged head projecting outwards at a short distance from each fulcrum-pin. The fork *l* embraces the chock B, fitted with a metal fulcrum-plate on each side, having a series of inclined rows *n n*¹ *n*² of notches with which the fulcrum-pins in the forked lever D¹ engage successively. The outer pins are connected at one end to the chock B¹, and provided at their opposite ends with a series of holes *p p*, into one or the other of which, according to the size of the wheel, the corresponding pin is inserted.

In working with this apparatus the lever D¹ is first placed in the position shown by the dotted lines in Fig. 241, with each fulcrum-pin engaging in the top one of the notches of the inclined row

n of its corresponding fulcrum-plate; the lever D^1 is then moved downwards in the direction of the arrow until it is brought into about a horizontal position, when the chocks B B are drawn together, after which the lever D^1 is raised to its former position, and the fulcrum-pins are dropped into the next lower notches, the lever drawn down again, and so on, until the pins reach the lowest notches in the respective rows; the lever is then lifted entirely out of that row, and the fulcrum-pins are dropped into the highest set of notches of the row n^1 next behind, and the preceding operations are repeated, after which, if necessary, the notches of the inclined row n^2 may be brought into use, the lifting being continued until the plumb line a coincides with the centre of the hole, or with the point of the lower angle bracket b^1.

241.





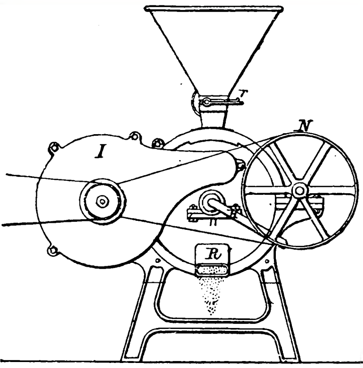
242.

In order to allow of the shifting of the lever from one row of notches to the other, the side rods F^1 are each provided with an elongated loop, fitting loosely on a pin, which curves upwards from each side of the chock. The forked lever D^1 is preferably constructed in two parts for the sake of convenience. The forked part is provided with a socket for receiving a plain straight iron lever D^1 of any required length, which is secured by a pin s passing through holes in the socket portion and the lever D^1. This pin is attached to the fork by a short chain, and after levelling up a wheel, and withdrawing the lever from the fork, the pin is inserted in one of several holes bored in one side of the chock B, to enable it to support the fork in its proper position, with the fulcrum-pins and crank-pins in a line with the rods F^1, in which position there is no tendency for the lever to rise by the strain due to the weight resting on the chocks, the cranks being then in the dead point.

For withdrawing the chocks from the wheels readily the chock B is formed with a narrow mortise on the top close to the tire of the wheel. This is lined with iron for the purpose of receiving the handle end of the lever D^1, which is curved, so that when the point enters the mortise the back of the curved part may be pressed against the wheel-tire for withdrawing the chock.

Corn-Dryer.—Figs. 243 to 247 are of Davey, Paxman, and Co.'s corn-dryer. It consists of a long cylinder, containing several internal cylinders. The cylinder B extends from end to end, and is formed with tapering end-pieces, which terminate in trunnions, one of which carries a spur-wheel, and is caused to revolve by the pinion. Steam is admitted into this cylinder by the pipe G, passing out through H. Outside the cylinder B are a number of perforated beaters D, arranged spirally, and having brushes which revolve in contact with the inner side of a larger cylinder. This latter forms an annular chamber, into which steam is admitted. Air is admitted to the outer cylinder K. In the annular space formed between the cylinder B and S a blast is admitted from the fan I, and

243.



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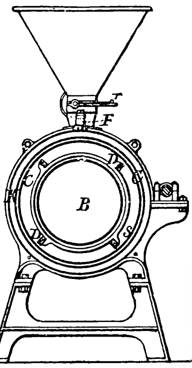

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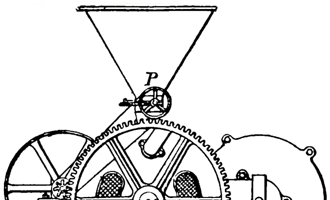
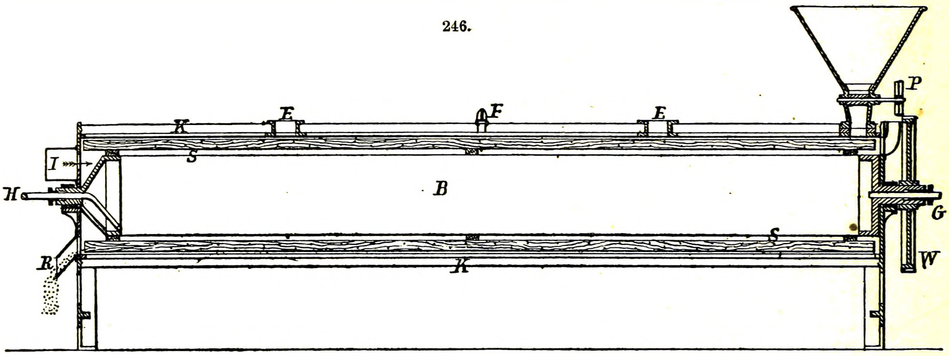
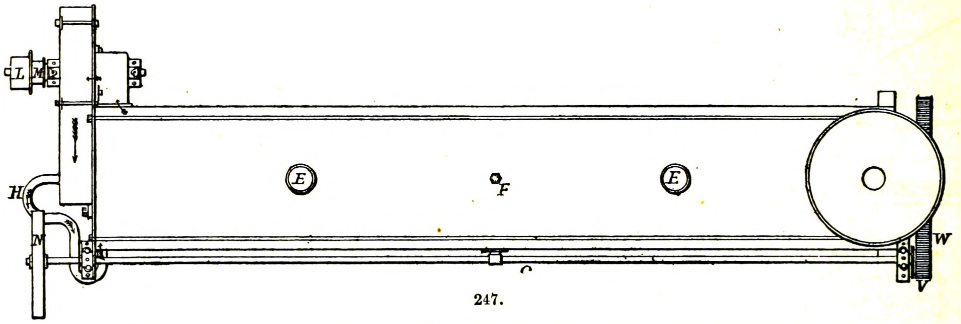


meets the corn as it advances through the machine. The corn is fed into the hopper, which is furnished at the bottom with a feeding roller, and it falls thence into the chamber which is in open communication with the perforated beater-bars. In traversing the length of the machine the corn is exposed to the drying action of the steam contained in the cylinder B and the annular space, and at the same time is subjected to the action of the blast from the fan, while it is violently agitated in its passage by means of the brushes and the holes in the beater-bars. E E are ventilators, F a steam-valve, *r* the hopper-valve, P L M pulleys, and W and V gearing. R is the outlet for the dried corn.

246.





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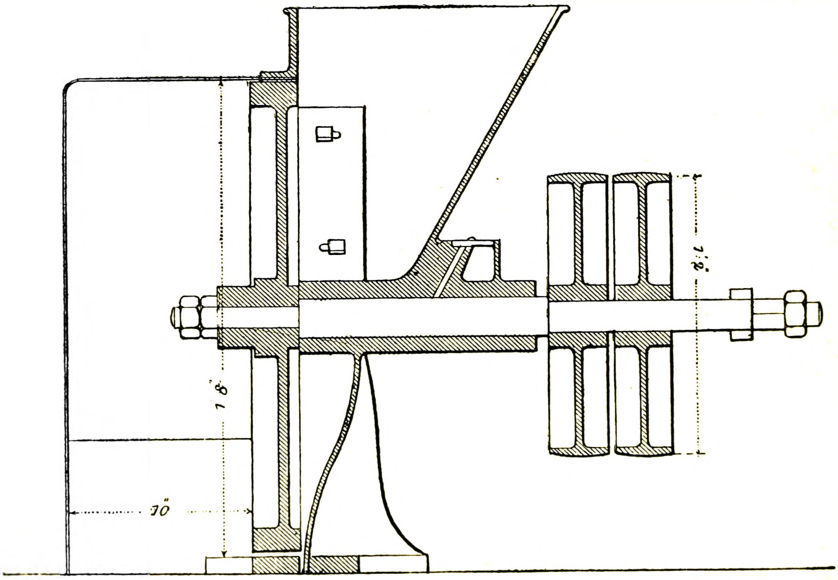
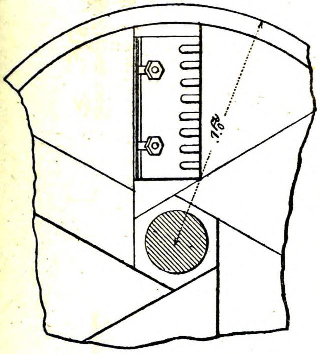
248.

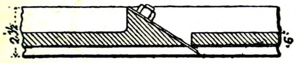


Root-Cutters.—Figs. 248 and 249 represent a disc root-cutter, constructed by M. Albaret. The disc has knives, Fig. 250, and is carried at the extremity of an iron axle revolving in a very long bush which traverses the hopper. The roots are thrown into a hopper, part of the vertical face of which is formed by the revolving disc. The weight of the roots causes them to descend against the knives of the disc, the cuttings falling into a frame of thin sheet iron to prevent loss from scattering. The disc may be turned by hand or steam power. When turned by hand, it makes about 40 to 50 revolutions per minute, and with steam attains about three times this velocity. To cut the roots into small prisms toothed knives are used, Fig. 249. To cut slices, for the toothed plate is substituted a straight cutter. The depth of the slices is regulated by the position of the cutters with relation to the plane of the disc. The arrangement of the hopper varies greatly, but it is preferably to be constructed of iron bars placed sufficiently near together to retain the roots.

Horse-Gears.—M. de Valcourt has proposed a horse-gear worked with cords, Fig, 251, of very simple construction. A conical piece of wood, bored throughout its axis, revolves on a vertical iron pivot fixed upon a massive pier or frame. The conical piece of wood, which forms the shaft of the gear, carries a number of wooden arms, in the direction of the spokes of a wheel, and kept in a horizontal plane by light iron ties connected to the summit of the central axis. The ends of the arms are grooved, and form, as a whole, an enormous pulley or wheel, the periphery of which is not continuous. In these grooves works an endless cord intended for the transmission of motion. The arms are 12 to 15 ft. in length, and are placed about 4 ft. above the ground, so that the horse walking between two traces attached to two arms, so as to form a chord with the rope, draws directly upon the machine. This horse-gear is well adapted for those situations where a source of power is required temporarily.

249.





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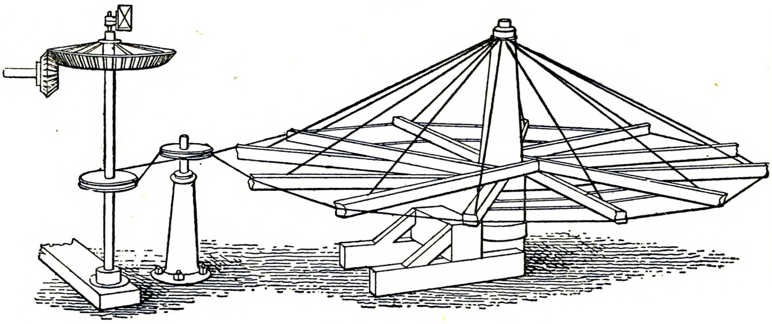
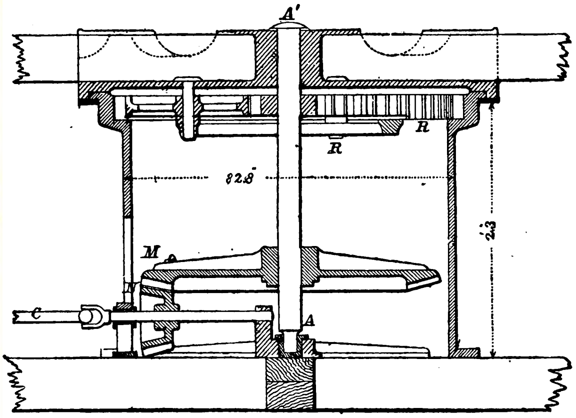
251.



Barrett's horse-gear, Figs. 252 and 253, is remarkable for the small space it occupies, but is somewhat complicated. The plate carrying the draw-bars pivots freely on the vertical axis A A¹. Three toothed wheels R are placed beneath this plate; these engage with a crown-wheel, and with the pinion keyed on the axle A A¹. The three wheels revolve with the same velocity, and for each revolution of the beam make a number of turns expressed by the inverse ratio of the number of their teeth to the number of teeth of the fixed crown. The motion of the three wheels R is transmitted to

252.



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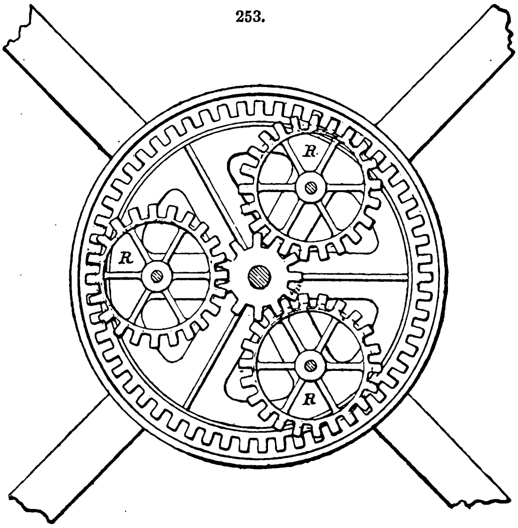
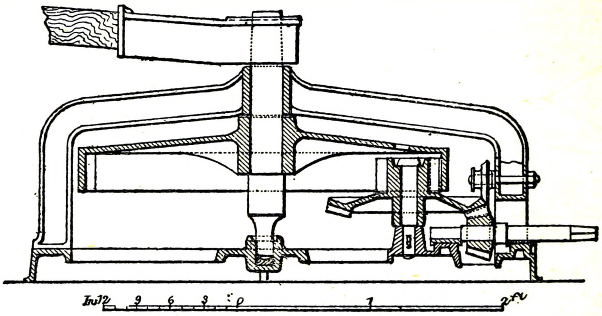


the pinion. Finally the rotation of the axle A is transmitted to the horizontal axle c by the wheel and angle-pinion M and N. If the fixed crown carries 56 teeth, the wheels R 22, and the pinion 11 teeth, and the ratio of the circumferences of the wheel and angle-pinion be equal to 5, the axle c will make a number of revolutions expressed by $\frac{56}{22} \times \frac{22}{11} \times \frac{5}{1} = 25 \cdot 45$ while the horse goes round once. A fault of construction of this gear may be mentioned, as it introduces a generally useful remark often applicable to gearing constructed with too great an economy, or in which too great an attempt has been made to reduce the dimensions of the mechanical parts. In a well-planned gear the ratio of the diameter of the pist or trace-ring to that of the first tooth-wheel should not be too great; for the effort exerted on the teeth of the first wheel is equal to the draw of the horse multiplied by this ratio. These would have to resist very great forces, and would be easily broken by any sudden check or pull given by the horse, if the length of the arms or beams of the gear had too great ratio to the radius of the first toothed wheel. The old gears in wood with their immense crown wheels of a diameter frequently greater than half that of the pist, were consequently well designed. Doubtless, this cannot be an absolute rule, and must be modified by exigencies of another nature, but the diameter of the first wheel should be at least one-fifth of that of the pist, except under special circumstances. E. R. and F. Turner, of Ipswich, have designed a horse-gear, Fig. 254, in which the main wheel is internally geared, and drives a pinion cast in the same piece with a bevel-wheel, and revolving on a pin keyed to the lower part of the frame. A bevelled roller running free on a pin passing through the side of the frame, bears against the upper edge of the bevel wheel, and keeps it steadily in gear with the pinion. The bed-plate is rectangular, and the bracket carrying the upper bearing of the main shaft is light and occupies but small space.

254.



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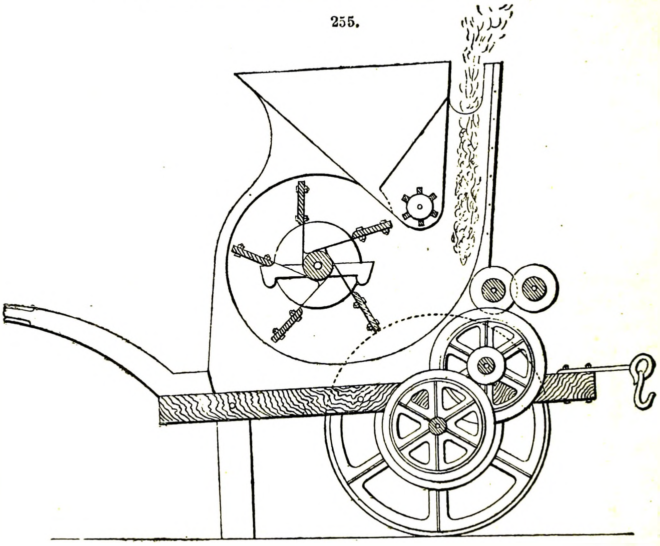


Sulphurator.—Although more closely allied to field operations, it is convenient here to describe an apparatus used for destroying mould upon the hop-plant, and termed a sulphurator, Fig. 255. Mould or white-blight, occasioned by the fungus Spærotheca Castagnei, allied to the fungus that causes the vine disease, known commonly as oïdium, was formerly terribly injurious to hop-plants; but like its ally, has been checked to a great extent by the application of sulphur put on usually before the hops are in burr or bloom with a sulphurator. This machine is drawn by a horse between the rows of plants. Two separate applications of sulphur are usually made; the first when the bine is just over the poles, the second just before the burr or bloom appears. About 50 lbs. per acre is put on at each application, at a cost of about 15*s*. per acre each time. The machine consists of a blower deriving its motion from the wheels of the carrier, and a chamber in which sulphur is burned, and through which the blast is directed. When hops are drying, it is usual to fumigate them with sulphur when evaporation is at its highest point. The sulphurous acid evolved by the sulphur bleaches the leaves of the reeking hops, and imparts to them a golden colour. About 10 lbs. of sulphur are burned for 300 bushels of green hops. If hops are much discoloured, sulphur fumes are passed through them twice while they are drying.

BELTS AND BELTING.

There is no simpler or more effective means of transmitting motion than that afforded by cords, bands, or straps. The manner in which this means is made to take effect, through the frictional adhesion between the surfaces of the belt and the pulley, conduces to the safety of the whole mechanism; for, if any unusual obstruction intervene, the belt merely slips, and shocks and breakage are prevented. The facility with which this communication of rotary motion may be established, or broken, at a distance, and under almost every variety of circumstance, has brought the band so extensively into use in machinery, that it is one of the principal channels through which work is transmitted.

A belt at a certain tension is not capable of exerting more than a certain definite force upon the pulley over which it passes, and it therefore occupies a certain time in communicating its own speed to the periphery of that pulley. The length of this time depends upon the masses which are to be set in motion along with the pulley, and the speed which is to be imparted to them, and until this time has elapsed the band has a slipping or sliding motion on the pulley. Belts are not, therefore, suitable for communicating a constant relation between several velocities with precision, on account of their being free to slip on the pulleys; but this very freedom to slip, as already pointed out, constitutes one of their great advantages when used in swift and powerful machinery, since it prevents those shocks which ordinarily take place when machinery which has been at rest is suddenly thrown into gear.

From a number of experiments which have been made, it has been ascertained that the loss due to this slip amounts to about two revolutions in a hundred. In practice this would be but a slight loss, and would not occasion any inconvenience; but where there is a long train of gearing, repeated from shaft to shaft by belts, the loss becomes serious, for after a succession of five speeds it amounts to no less than one-tenth of the calculated speed, while at the end of thirty-four speeds the velocity will be reduced by one-half. From these considerations it appears that where it is required to transmit speeds as near determinate as may be, by means of bands and pulleys, it will be necessary to increase the diameter of the driving pulley by its one-fiftieth part, or to diminish the driven pulley in the same ratio. The following table gives the percentage of slip in open and crossed belts of various lengths.

Parallel Belts. Length in Feet.	Percentage of Velocity lost by Slipping.	Crossed Belts. Length in Feet.	Percentage of Velocity lost by Slipping.
6	4·2	6	3·5
12	3·9	12	3·2
18	3·6	18	2·9
24	3·3	24	2·6
30	3·0	30	2·3
36	2·7	36	2·0
42	2·5	42	1·8
48	2·3	48	1·6
54	2·1	54	1·4
60	1·9	60	1·2

From this table it will be seen that the length of the belt exercises a considerable influence over the amount of its slipping, long belts being much less liable to slip than short ones; and it will also be seen that a crossed belt possesses a great advantage, in this respect, over an open or parallel belt.

Material and Manufacture.—Various substances, such as vulcanized-rubber, paper, sheet-iron, and others, have been, and are still, in certain special cases, employed for making belts; and their adoption has, in many cases, been followed by good results. But the most generally used material, and that which, after long experience, and numerous experiments with the various substitutes, has been almost universally adopted, is the best oak-tanned leather.

In the manufacture of belting, choice should be made of young hides, as these possess much more strength than the hides of old animals. After these have been carefully selected, they should be thoroughly tanned, by the old-fashioned oak-bark process; and the more slowly and perfectly this tanning is carried out, the better for all belting purposes will be the leather.

Previous to currying, the shoulders should be cut off, leaving only the best parts of the butts to be tanned for belting. It is the presence of these shoulder pieces in belts that often causes so much annoyance by making them run crooked; the shoulder naturally stretching in a direction contrary to the stretch of the butts.

Belts for service in dry, warm places may be made of coarse, loose leather, and will, under such conditions, be found to wear and work well; but for wet or moist situations, the finest and firmest white oak-tanned leather should be used.

Strength.—The strength of straps must, of course, be determined by the work they have to transmit. If a strap transmit a force of n horse-power at a velocity of v feet a minute, then the tension on the driving side of the belt is $\frac{33000\,n}{v}$ lbs., and this tension is independent of the initial tension producing adhesion between the belt and pulley. For example, let $v = 314·16$ feet a minute, which is the velocity of a 24-inch pulley at 50 revolutions a minute, and let 3 horse-power be transmitted, then $\frac{33000 \times 3}{314·16} = 312$ lbs., the strain on the pulley due to the force transmitted.

From the mean of a great number of experiments, which have been undertaken at various times, and under varying circumstances, the absolute strength of ordinary leather belting, three-sixteenths of an inch thick, appears to be about 3084 lbs. a square inch of cross-section. These experiments were made with belts of from 1 to 3 in. in width.

Good belting three-sixteenths of an inch thick should sustain for a long time, without any risk or serious wear, a tensional strain of 50 lbs. to each inch of width; or, according to Morin, about 355 lbs. the square inch of section.

The following table, showing the relative strength of leather and other belting, is taken from Cooper's 'Use of Belting.' The Centennial tests were made in the Philadelphia Exhibition, on July 3, 1876, in Messrs. Riehlé Brothers' testing machine; the others have been derived from various sources.

Material in Belt.	Size of Belt Tested.		Force Breaking the Belt.	Force Required to Break 1 Inch Width.	Force Required to Break 1 Square Inch.	Remarks.
	Width in Inches.	Thickness in Inches.				
	in.	in.	lbs.	lbs.	lbs.	
Leather	3	$\frac{1}{4}$	3750	1250	5000	Centennial tests. Oak-tanned.
„	3	$\frac{1}{4}$	3625	1208	4833	„ „ „ „
„	3	$\frac{1}{4}$	3500	1166	4666	„ „ „ „
„	3	$\frac{1}{4}$	3375	1125	4500	„ „ „ „
„	3	$\frac{1}{4}$	3250	1083	4333	„ „ „ „
„	3	$\frac{1}{4}$	3000	1000	4000	„ „ „ „
„	3	$\frac{1}{4}$	2250	750	3000	„ „ „ „
„	3	$\frac{1}{4}$	3250	1083	4333	Mean of the seven tests.
Raw hide	3	$\frac{5}{32}$	2875	958	6131	Centennial tests.
Sugar-tanned	$2\frac{3}{4}$	$\frac{1}{4}$	2000	727	2909	„ „
Rubber	3	..	3500	1833	..	„ „
„ 3-ply	3	$\frac{7}{32}$	3000	1000	4571	„ „
Leather	1	$\frac{3}{16}$	552	552	2944	Mean of five experiments. Ordinary leather.
„	2	$\frac{3}{16}$	1077	538	2872	„ five „ „
„	3	$\frac{3}{16}$	1522	507	2705	„ three „ „
Rubber, 3-ply	2	..	1211	605	..	„ five „ „
„ „	3	..	1763	587	..	„ five „ „
Leather	1	$\frac{3}{16}$	530	530	2836	
Rubber, 3-ply	1	..	600	600	..	
Leather	$1\frac{1}{4}$	..	1050	840	..	Oak-tanned.
„	$1\frac{1}{4}$	..	1850	1480	..	Page tannage.
„	..	..	..	..	3200	Good quality. Many tests.
„	..	..	..	..	4000	„ „
„	..	..	..	..	4278	English. Rankine.
Raw hide	..	..	..	..	6417	„ „
Leather	1	$\frac{3}{16}$	930	930	5000	Good new English.
„	1	..	1000	1000	..	
„	3	$\frac{7}{32}$	2025	675	3086	Towne. American.
„	..	..	..	..	4200	Ox. English. Rankine.
Flax	5	..	6272	1254	..	G. Spill and Co., London. Flax yarn cemented.
„	5	..	7448	1489	..	
„	10	..	16632	1663	..	
Leather	4	..	2100	525	..	
Calves' skin	..	..	..	..	1890	London Mech. Mag., 1863.
Sheep skin, Brazil	..	..	..	..	1610	„ „ „
Horse „	..	..	..	..	4000	„ „ „
„ „	..	..	..	..	3200	„ „ „
„ „	..	..	..	..	1680	„ „ „
Cow „	..	..	..	..	3981	„ „ „
Cotton duck	1	..	200	200	..	Centennial tests. "Union." Two shaved leathers, with cloth cemented between. No rivets in stronger piece.
Leather	3	..	3000	1000	..	
„	3	..	5625	1875	..	
„	1	..	..	1000	..	Good quality.

Durability.—The wearing of belts depends altogether upon circumstances. If they adhere well to the pulleys, and there is no slipping, but a continual adhesion while at work, leaving the pulleys clear, there is no perceptible wear while running with the hair side to the pulley; but put the rough or flesh side to it, and wearing will soon occur, from the friction caused by slipping on the pulleys.

Experience has proved that when the grain side of a belt is placed next the pulley, it will drive about thirty-four per cent. more than when the flesh side is placed next to it; but in connection with this, another question arises, namely, which side placed next the pulley is the more durable.

It is well known that the strength of leather is on the hair side, and it may be said to lie in about one-fourth of the thickness; when, therefore, this part of the belt is worn away, it will no longer be of much service. If, however, the flesh side be covered with a good coat of tanner's dubbing, and this be repeated for two or three successive days, it will acquire a smoothness, and a consequent driving power, almost or quite equal to that of the hair side. And as, by placing this side to the pulley, the strong side will be preserved from wear, the belt will be found, in many cases, to last six times longer when used in this way than when run on the hair side exclusively.

Loose-running belts will last much longer than those which must be drawn tightly to drive ; tightness being evidence of overwork and disproportion.

Preservation and Care of Belts.—Care should be taken that belts be kept soft and pliable ; and they should also be well protected from water and moisture. Penetrating oil should only be used when a belt has become very dry and harsh from neglect, for the frequent application of such oils renders the leather soft and flabby, causing it to stretch, and rendering it very liable to run out of line. A good dressing for leather belts is castor-oil; this may be applied by means of a rag or brush, while the belt is running, thus preventing loss of time by stoppage. The following is also a good dressing; one part of beef tallow and two parts of castor-oil, to be melted together and applied warm. The use of either of these will prevent the attacks of rats or other vermin, as none of them will touch the leather after one application of castor-oil.

Belts and all pulleys should be kept clean, and free from accumulations of dust and grease ; and especially from contact of lubricating oils, some of which permanently injure the leather.

To prepare a new belt, soak it for about ten minutes in water, then dry it for fifteen minutes, and afterwards brush it over two or three times with neat's-foot oil. When this is well dried the belt is ready to be put on. To keep it in good order it should be oiled once every two months in cold weather, and once a month in warm.

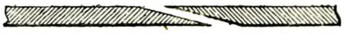
When a belt is dry and husky, but still pliable, a coating of blood-warm tallow, dried in by the heat of a fire or of the sun, will tend to keep it in good working condition ; the oil of the tallow passes into the fibre of the leather, serving to soften it, and the stearine is left on the outside to fill the pores, and thus preserve a smooth surface. The addition of resin to the tallow, for belts used in wet or damp places, will be of service, and help to preserve their strength. Belts which have become hard and stiff should receive an application of neat's-foot or liver oil, mixed with a small quantity of resin ; this prevents the oil from injuring the belt, and helps to preserve it. The quantity of resin, however, should not be sufficient to make the belt sticky. The following composition is recommended as a good one for preserving the pliability of belts :—1 gallon of neat's-foot oil, 1 gallon of tallow, and 12 ounces of resin, the whole to be dissolved by heat and well mixed. This is to be applied cold, the belt being first damped, excepting the joints, with cold water ; and the composition is to be well rubbed in. In winter a larger proportion of oil will be required.

The use of printers' ink has been recommended for increasing the adhesion of belts ; a case being on record where the slipping of a 6-inch belt, which had become very dry and smooth, was entirely prevented, for twelve months, by one application of this substance.

Belts stuffed with a composition formed of two parts, by weight, of tallow, one part of bag-berry tallow, and one of bees-wax, will run well for six months, without any attention, and will also be impervious to water. It is also said that a belt stuffed with this composition will last twice as long as one stuffed with oil. The composition is to be heated to the boiling point, and applied directly to both sides of the belt, by means of a brush ; and the belt is then to be held close to a red-hot plate, in order to soak in the bees-wax, which does not enter the pores of the leather from the action of the brush. Care must, however, be taken to have the leather perfectly dry, so as to prevent its burning. A kettle of this composition was placed over a blacksmith's fire and melted, a coil of perfectly dry 2-inch belting, about 16 feet long, was then put into it and boiled for forty-five minutes in the greatest degree of heat that could be produced by blowing the fire continually ; when taken out it was found that the texture of the leather was not the least injured by the heat of the composition. A piece of belting damped with water was next tried, and this was found to be burned and crisped in less than half a minute.

Permanent Joints.—In making permanent joints, the ends of the two pieces to be united must first be scarfed, or bevelled, as shown in Fig. 256 ; they may then be joined by either of the three following methods, each of which is extensively used.

256.



Glue the ends with ordinary hot glue, and bind them together with hand-screws until the glue is set, then drive in a number of shoemaker's pegs, dipping each one into hot glue before driving it in ; the number of pegs required will vary with the width of the belt. The pegs should afterwards be pared smooth on both sides, and the joint made of equal thickness with the rest of the belt. If not exposed to water, this joint will last as long as any part of the belt.

A good cement for joining leather, and one which has been found to stand well under heavy tests, is prepared as follows ;—Take ten parts of bi-sulphide of carbon and one part of oil of turpentine, and in this mixture dissolve sufficient guttapercha to render the composition moderately thick. The pieces of leather to be joined must first be freed from grease ; this is best accomplished by placing a cloth on the leather and pressing over this with a hot iron. After the joint is made, it is very important that it should be dried under pressure.

For making permanent joints in leather belts, take equal parts of common glue and isinglass, put them in a boiler or glue-pot, and add sufficient water to just cover the whole ; allow this mixture to soak for about ten hours, and then bring it to a boiling heat, and while it is in this state add pure tannin until the whole becomes ropy, or appears like the white of an egg. Apply this mixture warm, and rub the joint surfaces solidly together ; allow it to dry for a few hours, and it is ready for use. Joints put together in this way will not require riveting if they are properly done, for the cement itself is nearly of the same nature as the leather.

Laces and Lacing.—The usual method of joining the ends of a belt, that is, by means of leather thongs or laces, is undoubtedly the best as well as the most convenient, the thong being more easily obtained and applied than any of the numerous and ingenious substitutes which have been devised for securing the ends of belts.

From a great number of experiments which have been made with laces of various widths and thicknesses, for the purpose of ascertaining their strength, it has been found that the strength depends very much upon the part of the skin from which the thong is cut; one cut from near the backbone possessing, on an average, four times the strength of one cut from any other part.

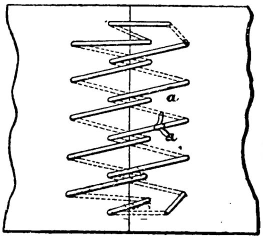
Eel-skin laces are, undoubtedly, the strongest laces or strings that can be obtained for lacing belts; they will withstand rough or hard usage, and will outlast any belt or ordinary lace. They are prepared by thoroughly drying the skins, and then slitting them lengthwise; and they can easily be prepared for use within three hours from the time of catching the eels.

In punching belts for lacing, the belt is weakened to the extent of the sum of the diameters of the holes, when the same are in a straight line across the belt. From this it will be seen that the best punches for cutting the lace-holes are those possessing an oval section, as they cut away less of the cross-section of the belt and still give ample space for the lacing.

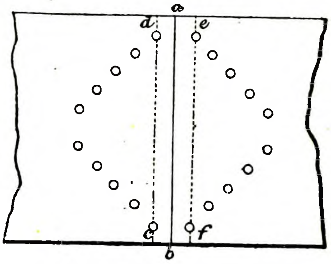
It is the practice of some engineers to cross the laces on both sides of the belt, while others cross them on the outside only, laying the strands evenly on each other in the line of motion on the pulley side of the belt, which experience proves to be the better way.

In Fig. 257 is shown a method of lacing without crossing by means of double rows of holes. In this arrangement the two ends of the lace *a a*, are tied in the middle of the belt. Experience has proved that when a belt is laced in this manner, the lace will last twice as long as when crossed.

257.



258.



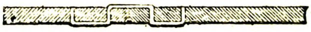
The best position for the holes, as proved by a number of experiments, is that shown in Fig. 258, since by this arrangement the cross-section of the belt is only weakened by two holes in any place. In the first experiments which were made with this system of lacing, the line *a b* was not cut, and the invariable line of fracture, which always commenced first at the edges, passed through the holes nearest to the same, and continued across in the same straight line, was *c d* or *c f*. The belt was then cut through the line *a b*, and after being securely laced it gave the following results:—The tearing began at the holes at five-eighths of the breaking-strain, and continued until the lacing tore out at the end holes, when the rest went suddenly. After being subjected to one-half of the breaking-strain for twenty-four hours, a slight addition to the weight caused the holes to tear, and, after commencing, the tearing continued rapidly until the end holes tore out, when the whole went suddenly, as before. After being subject to the same strain for forty-five hours, the effect was as above stated. But after being subject to one-third of the breaking strain for one week the holes showed no signs of fracture.

The tearing out of lace-holes is often attributed to bad belting, when in reality the fault consists in having the belt too short, and trying to force the ends together by lacing; and the more the leather has been stretched in the process of manufacture, the more likely is this accident to occur.

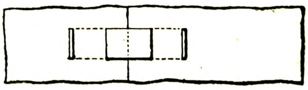
It has been proposed, as a means of strengthening laced belts, to employ large oval eyelets with broad flanges, to clasp or confine the material. These eyelets would not only materially strengthen the belt by distributing the strain round the whole of the circumference of the hole, instead of its being directed all to one part, as is the case when the holes are not so protected; but they would also preserve the holes from the rending action of the lacing, which must have some effect upon the portions in contact, as no belt can be laced so tight that the lacing will not rend to some extent.

The following method of lacing a quarter-twist belt is recommended as a means of equalizing the strain on both sides of the leather. Put the belt on, and bring the ends together in the usual way, then turn one end inside out and lace. The belt will then run first one side out and then the other, and will be found to draw on both sides alike.

259.



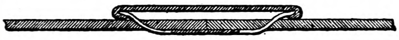
Belt-Hooks and other Fastenings—The Champion Belt-Hook.—This hook, which is shown in Figs. 259 and 260, possesses a substantial double bearing, which precludes the possibility of its tearing out; it is less expensive than the Blake stud; and although it costs more than the "C" hook, it is in the end cheaper, as it retains its original shape in the belt, and consequently can be used over and over again. This can be adjusted in little time and with great ease; shortening a belt or taking up slack is quickly accomplished; and few other belt-fastenings are equal to it for strength.

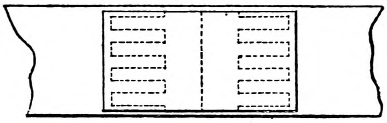


260.

The Lincolne Belt-Fastener.—This is one of the most ingenious forms of belt-fastener now in use, affording as it does a very strong and yet light joint by simple means; and it is as applicable to use with belts of indiarubber as it is with those of leather. This fastener is of Canadian invention. It consists of two pieces of tough, curved plate, tinned to preserve them from oxidation. The buckle proper is curved as shown in Fig. 261, and it is formed with a series of teeth at each end; these teeth are shown by the dotted lines in Fig. 262. It will be seen that the width of this buckle is rather less than the width of the belt. In applying this fastening, the ends of the belt are pierced from the inside with an awl, or a special tool for the purpose, in a somewhat slanting direction, and the points of the teeth are inserted into these holes, in such a manner as to project at the opposite side to that at which they are inserted. The plate cover, or clasp proper, is then slipped over the projecting teeth, thus tying them securely fast, and making the complete buckle. With very wide belts several such buckles are required.

261.





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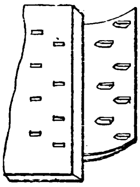
263.



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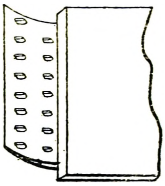
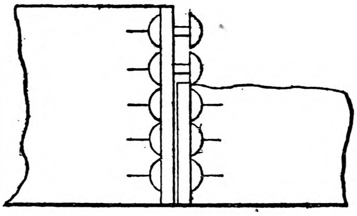
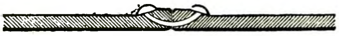


Wilson's Belt-Hooks.—These hooks are made in two forms. Fig. 263 is to be used with belts running at high speeds over small pulleys; and for making permanent joints, instead of the ordinary cemented and pegged joint. Fig. 264 is intended to take the place of the ordinary laced joint; by its use the strain is brought to bear on four or five times as many places as it would be if laces were employed, besides which, the belt is not weakened by having part of its substance removed by punching holes for the laces. To apply these hooks, they should be laid on a bench, or some other firm and solid place, with the teeth upwards, and the belt should then be driven down as tight as possible to the plate by means of a shoemaker's hammer. The teeth of the hook, Fig. 263, are made of sufficient length to come through the belt, and are to be clenched down and forced well into the substance of the leather. It is claimed that belts fastened by these hooks can be mended in one fourth of the time that would be required with laces; and they are also said to be one of the best fasteners for rubber or paper belts.

Blake's Belt-Studs, the form and manner of inserting which are shown in Figs. 265 and 266, are recommended as being both better and cheaper than either laces or hooks. They are made of such a form as to grip nearly the entire width of the belt, and, therefore, as they require no punched holes, the strength of the belt is but very slightly reduced; whereas the available sectional width of a laced belt, with ordinary punched holes, is generally reduced by one-third. By the use of these studs the edges of the belt are kept close together, but the studs do not touch the pulleys. Belts which have become too rotten to hold laces, may be securely fastened by this means, for the studs will hold until the leather is completely worn out. They also constitute an efficient fastening for use in damp places. In leather belts, the slits for inserting these studs should be made one-quarter of an inch, and in rubber belts three-eighths of an inch, from the ends, and the studs should be inserted half-an-inch apart. The smallest size of these studs, No. 6, are used for such purposes as joining the belts of ordinary sewing machines; No. 5 for 2-in. belts; and Nos. 1 and 0 for 4 and 5-ply rubber, and for double leather belts.

265.





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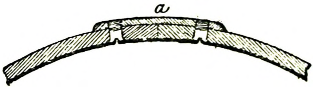
267.



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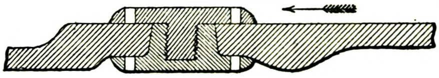
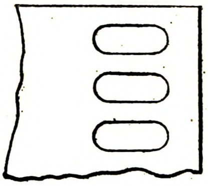


In Fig 267 is shown a method of joining the ends of belts, which is much recommended. The plate *a* is of brass, curved to the shape of the pulley, and is rather narrower than the belt. This plate laps the joint and receives countersunk-head screws from each end of the belt.

Fig. 268 shows another method of fastening the ends of a belt by means of screws, which has been very successfully adopted in practice. When this system is adopted, the belt must always travel in the direction of the arrow, and never be allowed to run against the joint.

In Figs. 269 to 271 is shown a method of joining the ends of a belt, without the aid of either laces, hooks, or screws. Two or more oval slots, Fig. 269, are made near one end of the belt to be joined; and in the other end of the belt, Fig. 270, D-shaped slots are made, the material being cut through the middle of the straight side of the D, by an incision parallel to the length of the belt, thus dividing the end into T-shaped parts. The ends of the belt are scarfed, so that when engaged, they will lie closely to the body of the belt. In connecting the ends of the belt, the T-shaped parts are twisted a quarter-way round, and passed through the oval slots in the other end, and then straightened up again, thus locking the ends together.

269.



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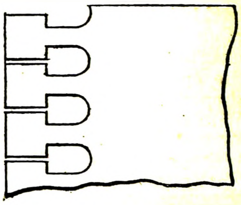
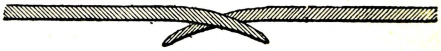




271.

General Conditions affecting the Running of Belts.—In order that belts may run well they should be perfectly straight, and of equal thickness throughout their length; and they should have but one laced joint. The ends to be laced should be cut at right angles to the sides, and the holes should be oval punched. The lacing must be put in evenly, of equal strength to the belt, and there must be no crossing of laces on the inside.

In the preparation of long belts, great care should be taken in selecting the pieces to have them of equal thickness, and the ends of the several pieces should be evenly scarfed or bevelled, and united in some permanent manner. If copper or other rivets are used, the heads should be let in rather below the inside surface of the belt, to prevent contact with the pulley, and the washers should be placed on the outside surface. If the bevelled and lapped ends are sewed, the wax-end should be laid in flush, on the inside of the belt, to prevent wear.

Care should be taken to have all belts run free and easy, with as much slack as possible on the upper side. When the slack is in this position, its weight forms a most effective tightener, increasing the adhesion of the belt, by enlarging its circumferential contact with the pulleys. The amount of this slack should be sufficient to allow the return, or following, side of the belt, to run with a gentle undulating, or waving motion; all the tension being on the leading, or driving, side of the belt. When a belt is so run, without sliding on the pulleys, it will wear for a great length of time. For, although a belt may be heavily loaded, yet if at every revolution it has an opportunity of relief from its tension, so as to be able to contract to its natural texture, it will prevent it from breaking by the stress upon it. If, however, it be kept strained tight on both sides of the drum, it will soon show signs of wear, especially by cracks at the edges, and it will last but a short time. With loose running belts, also, the shaft and all bearings will be subject to much less strain; and may, consequently, be made lighter than they otherwise could.

The use of tighteners, with horizontal and inclined belts, should be avoided in all possible cases; and they should only be adopted after every other means of obtaining the requisite power from the belt has been tried and failed. When used they should be of as large a diameter and as free running as possible, with perfectly smooth, flat faces, and should, of course, be applied to the upper, or slack side of the belt.

Vertical, or perpendicular, belts, require to be run tighter than horizontal ones, in order to insure contact with the bottom pulley; they must therefore, be kept tightly strained, and they should be made of leather which has been well and thoroughly stretched in the process of manufacture, to lessen their tendency to stretch by their own weight while hanging on the pulleys. If tighteners be used with vertical belts, they should be fixed in such a manner as to operate by their tendency to fall towards a horizontal position.

Belts should be applied with the grain side to the pulley; so used, they will not only do more work, but they will last longer than if used with the flesh side to the same. The fibre of the grain side is more compact and fixed than that of the flesh side, and more of its surface is constantly brought into contact with, or made to impinge upon the particles of the pulley. The two surfaces, that of the band and that of the pulley, should be made as smooth as possible, especially as the surfaces in contact increase in extent, and the more they impinge on each other. The smoother the two surfaces, the less air will pass under the band, and between it and the pulley, as the air prevents contact, and the greater will be the contact, and the more machinery will the band drive. The more uneven the surface of band and pulley, the more strain will be necessary to prevent the band from slipping. What is lost by want of contact, must be made up by extra strain upon the band, in order to make it drive the machinery required; oftentimes, if the band is laced, causing the lacings to break, the holes to tear out, or fastenings of whatever kind to give away. Bands used with the grain side to pulley will not crack; as the strain, in passing the pulley, is thrown on the flesh side, which is not liable to crack or break; the grain not being strained any more than other portions of the band.

Belts should not be worked up to their full power, and they undoubtedly give the best results when running on large pulleys at a high velocity; the driving side being placed below, as already pointed out. The best speed for economy of working is from 1200 to 1500 ft. a minute, and it should never exceed 1800 to 2000 ft., or the extra strain thus occasioned will seriously reduce the durability of the belt.

Horizontal, inclined, and long belts give a much better effect than vertical and short ones; for a long slack belt will work for years, while a short one under heavy strain is soon destroyed.

Care must, however, be taken that the length be not too great; as instance the following case. A 60-in. pulley, at 45 revolutions a minute, drove a 15-in. pulley, about 50 ft. distant, by an 11-in. belt, 109 ft. long. The tops of the pulleys were nearly on the same level, and the belt was crossed. This belt was continually flapping about, soon became crooked and irregular in width, and was frequently torn asunder, at the lacings, by excessive tension; and the whole arrangement proved very troublesome until changed to the following;—The speed of the 60-in., and the diameter of the driven pulley, were doubled, and the distance between their centres was reduced to 15 ft. The belt now drives with more power, gives greater regularity of speed, and works better every way.

Sometimes a belt will be found to work badly from causes quite outside its own motion and proportions; as instance the following case in practice. A 46-in. pulley on the line-shaft, drives a 60-in. pulley on a 4-in. shaft, at the rate of 73 revolutions a minute, by means of a 12-in. open belt. This latter shaft is situate 7 ft. 8 in. below, and 2 ft. in front of the line-shaft, and carries on its centre an 8-ft. fly-wheel, weighing 3750 lbs.; and it has a crank with a double pin on its overhanging end, which is connected with and drives two marble saw frames, one very heavy, the other of medium size. The belt runs slack and free, and was not touched at the lacing during six months of very steady and satisfactory running. Before the 8-ft. fly-wheel was put on, a 6-ft. fly-wheel of about 1450 lbs. weight was used, which a long, troublesome experience proved altogether insufficient. The belt had to be run very tightly; it tore frequently at the lacings, even when the laced ends were doubled to make the stronger joining; and at all times while running, the lack of momentum in the wheel caused unsteadiness of motion in the whole system of gearing in the mill.

Slipping.—It is a well-known fact in connection with belts, that they require a greater degree of tension, to prevent their slipping, when running at a high than they do at a low speed. Various reasons have at different times been advanced to account for this; but the following appears to be the true cause.

The centrifugal force of the belt, acting against its tension, causes it to slacken its grip of the pulleys, and this force naturally increases in direct proportion with the speed. For it can be proved from the elementary laws of dynamics, that if an endless band, of any figure whatsoever, run at a given speed, the centrifugal force produces a uniform tension, at each cross section of the band, equal to the weight of a piece of the band, whose length is equal to twice the height from which a heavy body must fall in order to acquire the velocity of the band.

If w be the weight of a unit of length of the band, v the speed at which it runs, and g the velocity produced by gravity in a second $= 32$; then the *centrifugal* tendency, as it may be called, has the following value; $\frac{w\,v^2}{g}$.

The effect on the band in motion is, that at any given point, the tension which produces pressure and friction on the pulleys, or available tension, as it is called, is less than the total tension, by an amount equal to the centrifugal tension; for this amount is employed in compelling the particles of the band to circulate in a closed or endless path. It is, of course, to the total tension that the strength of the band is to be adapted, therefore the transverse dimensions of a band, for transmitting a given force, must be greater for a high than for a low speed.

Shafts and Pulleys—Shafts.—In the placing of shafts that are to be connected with each other by belts care should be taken to obtain a proper distance between them. For if the distance be too great the weight of the belt will produce a very heavy sag, and will draw so hard upon the shaft as to produce great friction in the bearings; the belt at the same time having so unsteady and flapping a motion, as will tend very soon to destroy both itself and the machinery. If, on the other hand, the shafts are brought too close together, there will be a loss of driving power from the belt, on account of the reduction of the surface-contact between itself and the pulleys. A general rule, and one which has been found to give very good results in practice, is as follows;—Where narrow belts are to be run over small pulleys, 15 ft. is a good average. For larger belts working on larger pulleys the distance should be from 20 to 25 ft.; while shafts on which very large pulleys are to be placed should be from 25 to 30 ft. apart. Another rule gives the distance between shafts to equal ten times the diameter of the smaller pulley.

Shafts which are to be connected by belts should never, if it can possibly be avoided, be placed one directly over the other; for in such a case the belt would require to be kept very tight to do the work. It is desirable that the angle of the belt with the floor should not exceed 45°. Circumstances, however, generally have much to do with the arrangements, and the engineer must use his judgment, making all things conform, as far as may be, to general principles, always bearing in mind that the distance between the shafts should be such as to allow of a gentle sag to the belt when in motion.

Wrought-iron shafting of 1 in. diameter will transmit between 14 and 15 horse-power at 100 revolutions a minute, before there is any set twist; a shaft 2 in. in diameter will transmit 100 horse-power before twisting; and a shaft of 4 in. diameter, and running at the same velocity, is capable of transmitting 800 horse-power before twisting, but will frequently be broken by very much less power if out of line; while 1 or 2-in. shafting, being flexible, will hardly be influenced by small variations. It will be seen from this that torsion is hardly to be considered in shafting a mill, as it will require larger shafting to prevent springing by transverse pressure than it does for torsion; a shaft being seldom twisted off, but generally broken by jar of gears, by being out of line, or by transverse strains. In advocating the use of small shafting it is not pretended that, theoretically, there is any saving of friction in transmitting the same amount of power, but that in most cases the diameter is larger than required, as the transverse strain requires a larger diameter than the torsional, as above stated. For it evidently requires the same amount of friction to transmit a given power with a 1-in. as it does with a 6-in. shaft, as the 6-in. shaft would, of course, run very much slower.

The following table gives the horse-power transmitted by shafts of various diameters at a speed of 100 revolutions a minute;—

First Movers.				Second Movers.				Third Movers.					
Diam.	Horse-power.	Diam.	Horse-power.	Diam.	Horse-power.	Diam.	Horse-power.	Diam.	Horse-power.	Diam.	Horse-power.	Diam.	Horse-power.
in.		in.		in.		in.		in.		in		in.	
3	27·00	$7\frac{3}{4}$	465·48	$2\frac{1}{2}$	31·25	$7\frac{1}{4}$	762·14	1	3·00	$2\frac{3}{16}$	31·40	$3\frac{3}{8}$	115·33
$3\frac{1}{4}$	34·33	8	512·00	$2\frac{3}{4}$	41·59	$7\frac{1}{2}$	843·74	$1\frac{1}{16}$	3·59	$2\frac{1}{4}$	34·17	$3\frac{7}{16}$	121·10
$3\frac{1}{2}$	42·87	$8\frac{1}{4}$	561·51	3	54·00	$7\frac{3}{4}$	930·96	$1\frac{1}{8}$	4·27	$2\frac{5}{16}$	37·09	$3\frac{1}{2}$	128·62
$3\frac{3}{4}$	52·73	$8\frac{1}{2}$	614·12	$3\frac{1}{4}$	68·66	8	1024·00	$1\frac{3}{16}$	5·02	$2\frac{3}{8}$	40·18	$3\frac{9}{16}$	135·63
4	64·00	$8\frac{3}{4}$	669·92	$3\frac{1}{2}$	85·74	$8\frac{1}{4}$	1123·02	$1\frac{1}{4}$	5·85	$2\frac{7}{16}$	43·44	$3\frac{5}{8}$	142·90
$4\frac{1}{4}$	76·76	9	729·00	$3\frac{3}{4}$	105·46	$8\frac{1}{2}$	1228·24	$1\frac{5}{16}$	6·78	$2\frac{1}{2}$	46·87	$3\frac{11}{16}$	150·42
$4\frac{1}{2}$	91·12	$9\frac{1}{4}$	791·45	4	128·00	$8\frac{3}{4}$	1339·84	$1\frac{3}{8}$	7·79	$2\frac{9}{16}$	50·47	$3\frac{3}{4}$	158·20
$4\frac{3}{4}$	107·17	$9\frac{1}{2}$	857·37	$4\frac{1}{4}$	153·52	9	1458·00	$1\frac{7}{16}$	8·91	$2\frac{5}{8}$	54·26	$3\frac{13}{16}$	166·24
5	125·00	$9\frac{3}{4}$	926·86	$4\frac{1}{2}$	182·24			$1\frac{1}{2}$	10·12	$2\frac{11}{16}$	58·23	$3\frac{7}{8}$	174·55
$5\frac{1}{4}$	144·70	10	1000·00	$4\frac{3}{4}$	214·34			$1\frac{9}{16}$	11·19	$2\frac{3}{4}$	62·39	$3\frac{15}{16}$	183·13
$5\frac{1}{2}$	166·37			5	250·00			$1\frac{5}{8}$	12·87	$2\frac{13}{16}$	66·35	4	192·00
$5\frac{3}{4}$	190·10			$5\frac{1}{4}$	289·40			$1\frac{11}{16}$	14·41	$2\frac{7}{8}$	71·29	$4\frac{1}{16}$	201·12
6	216·00			$5\frac{1}{2}$	332·74			$1\frac{3}{4}$	16·07	$2\frac{15}{16}$	76·04	$4\frac{1}{8}$	210·56
$6\frac{1}{4}$	244·14			$5\frac{3}{4}$	380·20			$1\frac{13}{16}$	17·86	3	81·00	$4\frac{3}{16}$	220·28
$6\frac{1}{2}$	274·62			6	432·00			$1\frac{7}{8}$	19·77	$3\frac{1}{16}$	86·16	$4\frac{1}{4}$	230·29
$6\frac{3}{4}$	307·54			$6\frac{1}{4}$	488·28			$1\frac{15}{16}$	21·81	$3\frac{1}{8}$	91·38	$4\frac{5}{16}$	240·60
7	343·00			$6\frac{1}{2}$	549·24			2	24·00	$3\frac{3}{16}$	97·15	$4\frac{3}{8}$	251·22
$7\frac{1}{4}$	381·07			$6\frac{3}{4}$	615·08			$2\frac{1}{16}$	26·32	$3\frac{1}{4}$	102·98	$4\frac{7}{16}$	262·14
$7\frac{1}{2}$	421·87			7	686·00			$2\frac{1}{8}$	28·78	$3\frac{5}{16}$	109·04	$4\frac{1}{2}$	273·37

Pulleys.—The faces of all pulleys must be true and concentric, and their shafts parallel to each other; for, if this is not the case, the belts running upon them will require guiding, and this will cause their edges to wear very rapidly. Pulleys for shifting belts should be straight-faced, unless the shafts are far apart, in which case they may be slightly convex.

Flanges to pulleys and belt-guides should be avoided, except for pulleys on upright shafts, or where two belts run closely together on the same pulley, or on two adjoining pulleys of like diameter; and even in these cases with a high speed they may often be discarded.

To find the ratio of the speed of turning of two pulleys connected by a band;—Measure the effective radii of the pulleys from the axis of each to the centre line of the belt; then the speed of turning will be inversely as the radii. The effective radius of a pulley is equal to the radius plus half the thickness of the belt.

Pulleys covered with leather will drive from 25 to 50 per cent. more than smooth iron pulleys.

From a number of experiments carried out by Hoyt, Brothers, of New York, the percentage of resistance of bands on various pulleys was found to be nearly as follows; and this percentage will indicate the relative working value of each pulley respectively:—

Leather-covered pulleys	36 per cent.
Smooth polished iron	24 to 30 ,,
Rough turned iron..	15 ,,
Polished mahogany	25 ,,

When it is required to cover an iron pulley with leather, the leather should first be steeped for a few hours in a strong infusion of gall-nuts. Then cover the metal with a layer of hot glue, and apply the leather to it on the fleshy side; considerable pressure should be employed in order to ensure perfect contact between the two substances, and the pressure should be maintained during the whole time that it is drying. When fastened in this manner the leather will resist the effects of moisture, and may be torn sooner than separated from the metal. The following method of preparing the glue for this purpose is much recommended;—Soak the glue in good cider-vinegar, and, after it has dissolved, add to every quart of the solution 1 oz. of Venice turpentine; then let it cook for five or six hours, and it will be ready for use. Large pulleys and drums may be covered with narrow strips of leather wound round spirally; but narrow pulleys should be covered by leather of the same width as the pulley face.

Cast-iron pulleys of large diameter are not suited for running at high velocities, owing to unequal shrinkage in cooling and other imperfections. Running slow the centrifugal force has but little effect; but as the centrifugal force is as the square of the velocity, it is not so easily overcome in rapid motions. Making the rim of the pulley thicker only increases the centrifugal force, as this force is proportional to the weight of the mass in motion, and consequently nothing is gained by the extra iron. To overcome this difficulty large pulleys have generally been constructed of wrought iron, the tensile strength of which being much greater than that of cast iron, enables the rim of the pulley to be made much thinner, and the centrifugal force to be consequently very considerably reduced. But the best and cheapest method of construction for large pulleys appears to be that adopted by Daniel Hussey, of Lowell, Massachusetts, which he thus describes;—White pine felloes made of 1-in. boards, and breaking joints for the rim, are built on cast-iron hubs and arms. Now the centrifugal force of material is as the specific gravity, and the specific gravity of cast iron is thirteen times that of pine, hence the centrifugal force must be thirteen times greater; but the tensile strength of cast iron is only two to one of that of pine, therefore the rim of a pulley made of white pine felloes, will sustain from four to six times the centrifugal force of a rim made of cast iron; that is, the same diameter with white pine felloes will run at more than double the velocity without being torn asunder. It is less likely to be broken by jar or blow, and is less than half the weight, and will therefore consequently take less power to run it. Hussey had a pulley made in this way 16 ft. diameter and 4 ft. wide running at a speed of 90 revolutions a minute, and another, 17 ft. diameter and 62 in. wide, at 100 revolutions a minute, driving on to one made in the same way 4 ft. diameter, and running 425 revolutions a minute. Both of these were said to work well.

It will be seen from the following paragraph that great diversity of opinion exists as to the proper convexity to be given to the faces of belt pulleys; the proportion of rise to width of pulley face varying in the different formulæ from one-tenth to one ninety-sixth. The rounding should evidently be made as slight as is consistent with security, since every deviation from the cylindrical form is accompanied by a loss of force. For in their progress round the pulleys the different parts of the belt are stretched and relaxed alternately. Now if the material of the belt were perfectly elastic, the force expended in the distension would be reproduced on the contraction of the belt. The amount of loss due to this imperfect elasticity is not known, but it will certainly be increased in proportion to the disturbance of the particles of the belt, that is, the higher the rounding of the pulleys the greater will be the loss due to this cause.

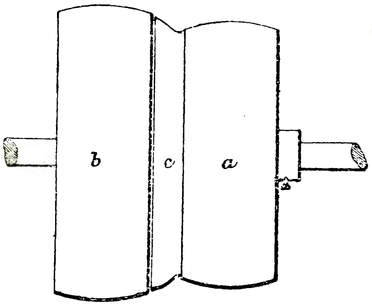
Morin says;—The pulleys over which belts pass ought to have a convexity equal to about one-tenth of their breadth. Molesworth; belt pulleys should be made slightly convex, in a ratio of half-an-inch to each foot of breadth. Another proportion gives one-eighth of an inch rise for 8 inches of width. And another one-eighth of an inch to the foot. The proportion of rise to width will require to be greater for narrow pulleys than for wide ones.

It may be observed that this very provision, namely, the rounding of the face of the pulley, which keeps the belt in its place so long as the machinery is in proper action, tends to throw it off whenever the resistance becomes so great as to cause a slipping. To maintain a belt on a pulley it is necessary to have the advancing part in the plane of the wheel's rotation.

Many reasons have been advanced to account for the belt running to the higher part of the pulley, but the chief cause appears to be the following. That edge of the belt which is towards the larger end of the cone, is more rapidly drawn than the other edge; in consequence of this, the advancing part of the belt is thrown in the direction of the larger part of the cone, and this obliquity of advance towards the cone must lead the belt on to its higher part.

In Fig. 272 is shown an improved form of fast and loose pulley, introduced in 1876 by Crafts and Filbert. In this arrangement the loose pulley *a*, is made 2 in. less in diameter than the driving pulley *b*, and is provided with a conical flange *c*, by means of which the belt mounts to the driving pulley. The difference in diameter of the two pulleys will slacken up the belt 3 in., taking the strain off the belt and the friction from the pulley, and allowing the belt to contract when thrown off the tight pulley. By these means the belt has a chance to give and take, as it is always in a slack condition when on the loose pulley, and should contract enough to keep it tight for a long period; for whatever will relieve the belt of strain will add to its durability. There is considerable wear and tear on a belt in shifting it with the ordinary pulley; for in starting a heavy machine it is necessary to hold the belt on with the shifter until the machine is in full motion, and during this time the edge of the belt is rubbing against the shifter, tearing up the corners of the laps and wearing away. The flanged pulley, however, requires very little aid from the shifter, for when the belt is brought to touch the flange it immediately climbs to the tight pulley, and remains there, starting the machine quickly.

272.



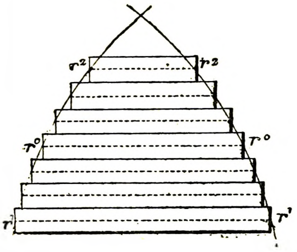
Cone Pulleys.—Cone pulleys consist of a series of pulleys of different diameters, and are generally formed in one casting, They are fixed in one order of succession on the driving shaft, and in the reverse order on the driven; the sum of the respective diameters of each pair being such that the same belt will run with equal tension on any pair. These pulleys are employed in lathes, and in other machines, where it is required at times to vary the velocity of the driven pulley, while the rate of motion of the driver remains constant. For crossed belts these pulleys are equal stepped cones, so proportioned that the sum of the diameters of each belted pair is the same. For uncrossed or open belts a pair of equal and similar frustra of conoids, bulging in the middle, must be constructed according to the following formula. Let *c* denote the distance between the axis of the conoids, r^1 the radius of larger end of each, r^2 the radius of the smaller end; then the radius of the middle, r^0, is found as follows:

$$r^0 = \frac{r^1 + r^2}{2} + \frac{(r^1 - r^2)^2}{6 \cdot 28\, c}.$$

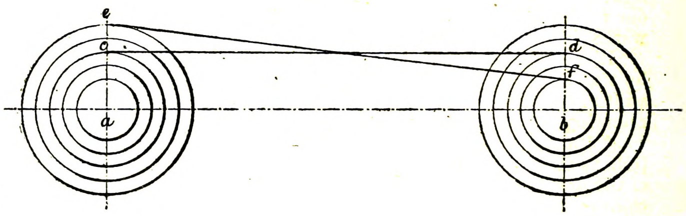
Having found the three points, r^1, r^2, r^0, Fig. 273, describe an arc of a circle passing through them, and upon this draw the faces of all the pulleys in the series, in the manner shown.

In order to show why an open belt would not have equal tension on all the pulleys of an equal stepped cone; let *a b*, Fig. 274, be two equal stepped cones on parallel axes. Now, if the sum of the diameters of the extreme pulleys *e f* be equal to the sum of the diameters *c d*, the connecting strips of the belt *e f* and *c·d* should be equal, for the enrolled parts are equal by the construction of the cones; but *e f* and *c d* cannot be equal, for they are not parallel, and hence it appears that *c d*, being at right angles to the shafts, is shorter than *e f;* therefore, in order to preserve a certain tension of the belt, when on the extreme pulleys, the middle pulleys must be larger than the size given by equal steps, in order to take up this difference.

273.



274.

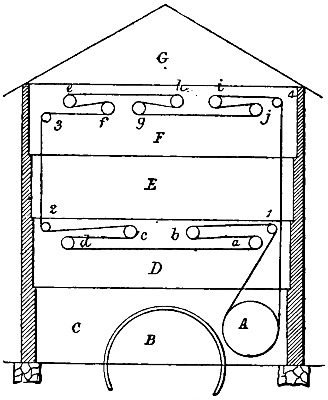


Arrangement of Belts.—In laying out the gear of a mill it is important to arrange the drums and belts in such a manner, that, so far as may be practicable, the stress of one belt upon the journals shall be counteracted by that of another belt in an opposite direction. Often, however, cases will arise in which it is compulsory to place the main shaft at the side of the mill; but this position should be avoided whenever possible, as it throws the whole of the strain upon one side of the journals and bearings, and consequently causes them to wear unevenly, and soon to become loose. The best position for the main shaft is undoubtedly the centre of the mill; the position of the secondary shafts being of minor importance.

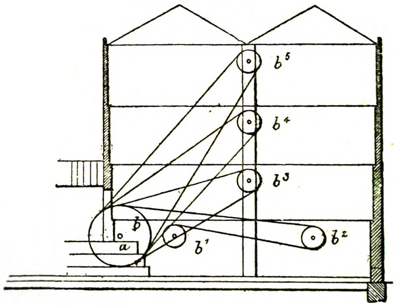
In some American factories one long belt is made to run the whole round, from top to bottom of the mill; turning every main shaft, passing where necessary over carrier pulleys, and working its way to and fro. This is not a good plan, as the belt is required to be of abnormal length; and, having all the stress upon it, it must be sufficiently wide to take off all the power. It is likewise more costly than necessary, besides possessing several other disadvantages.

This arrangement is shown in Fig. 275. A is the main driving pulley, from 8 to 12 feet in diameter, which is geared from and driven by the water wheel B; C is the basement, D the carding room, E the spinning room, F the weaving room, and G the dressing room. The lines of drums and shafting, in the carding and weaving rooms, are shown by the letters *a* to *j;* 1, 2, 3, and 4 are the binders or guides, to lead or bind the belt in the required direction. The lines of drums extend very nearly throughout the whole length of the mill inside, and, for a mill of 4000 spindles, are driven by two belts operating in the manner shown. These belts must each be about 320 feet long, and from 12 to 15 inches wide; and it will require from 600 to 700 lbs. of stout belt leather to make each one. They are undoubtedly bulky, ponderous, and unmanageable; and whenever a lacing breaks, to which accident belts are frequently liable, they are likely to run nearly or quite off the drums; and this would cause the stoppage of the whole of the machinery, besides requiring the work of some six or eight men, for several hours, to put them on again.

275.



276.



The simplest and best method of driving by belting, which is also the cheapest and the most durable, is to convey the power from the main driving shaft direct to each room by a separate strap; and if more than one shaft be required in any one of the rooms, to drive it direct from the other by a separate strap; apportioning the width of each belt to the power it is required to transmit, and where it is necessarily short, allowing a little extra width.

In Fig. 276 this method of laying out a mill is shown as applied to driving a mill of four stories, in which two shafts are required in the bottom room: these may both be driven direct from the first strap, in the manner shown in the figure. *a* is the main driving shaft, and is driven direct from the steam engine, or other motor, at the rate of 80 revolutions a minute; *b* is a strong well-balanced drum, of 15 feet diameter and about 3 feet wide, keyed on to the shaft *a*, and having therefore a surface velocity of about 3770 feet a minute. The pulleys b^1, b^2, b^3, and b^4 are each about 3 feet in diameter and 6 inches wide, they are keyed to the respective shafts which they have to drive, and will, in this case, make about 200 revolutions a minute; but their speed may, of course, be varied by altering their diameter. But whatever else is done, the speed of the straps must be kept up, for in this lies one of the great secrets of success in belt driving. The shaft A, if the power be steam, will be the engine crank shaft, and the drum upon it will act as a fly-wheel; for, without being heavy, it will have great *vis viva*, by reason of its great speed. This pulley must be turned a little convex at the centre of the place where each strap comes upon it, and there must also be a flat space of about 3 or 4 inches between each hump, so as to admit of each belt being boxed up separately, in order to ensure its running in its proper place. By these means, should any one of the belts break, it cannot in any way interfere with the others, as it runs in a separate box all the way up.

Length.—Having properly arranged and proportioned the main driving shafts and pulleys and arranged the machinery, the next thing to be done is to determine the lengths and widths of the several belts required.

To find the length and course of a belt, apply a tape-line or string to the pulleys where the belt goes, and then measure the length of the string by a two-foot rule; or make a drawing, full-size or to scale, and step dividers around the course of the belt. By means of such drawings the places where the belt passes the floors, and the like, can be also found. When it is not convenient to measure with the tape-line the length required, the following rule will be found of service;—Add the diameters of the two pulleys together, divide the result by 2, and multiply the quotient by $8\frac{1}{4}$; add the product to twice the distance between the centres of the shafts, which will give the length required.

To measure the length of a belt in coil;—Let D = mean diameter of the roll in inches, *d* the mean diameter of the eye of roll in inches, and *n* the number of turns.

Then the length $L = (D + d)\,n \cdot 1309$ feet.

Width.—The following rules for calculating the required width of leather belts are taken from Molesworth's Pocket-Book;—

V = Velocity of belt in feet a minute.
H.P. = Horse-power—actual—transmitted by belt.
S = Strain on belt in lbs.
W = Width of single belting—$\frac{3}{16}$ in. thick—in inches.

$$S = x + k\,x.$$

$$W = \cdot 02\ S.$$

$$x = \frac{33000\ \text{H. P}}{\text{V.}}.$$

$k = 1 \cdot 1,\ 0 \cdot 77$, and $0 \cdot 62$, when the portion of the driven pulley embraced by the belt = ·4, ·5, ·6, of the circumference respectively.

For double belting the width equals $W \times \cdot 6$.

Approximate rule for single belting $\frac{3}{16}$ inch thick;—

$$W = \frac{1100\ \text{H. P.}}{\text{V.}} \qquad [a]$$

"The formulæ given above apply to ordinary cases, but are inapplicable to cases in which very small pulleys are driven at high velocities, as in some wood-cutting machines, and fans. The acting area of the belt on the circumference of the driven pulley being so small, that either great tension or a greater breadth than that determined by the formula, is required to prevent the belt from slipping.

"In such extreme cases of high-speed belts, find the breadth of the first-motion belt by the formula for ordinary belting above (*a*), then if—

A = Acting area of first-motion belt.
v = Velocity of first-motion belt.
a = Acting area of high-speed belt.
V = Velocity of high-speed belt.

$$a = \frac{A\,v}{V}.$$

"The acting area of either belt = $l \times b$.

"Where l = length of circumference of driven pulley embraced by the belt; and b = breadth of the belt, therefore;—

$$b = \frac{a}{l} \text{ in the case of the high-speed belt.}$$

"If there is no first-motion belt exclusively for the machine it will be easy to suppose a case, from which the breadth of the high-speed belt may be calculated.

"Rule (*a*) is equal to 91·6 square feet of belt a minute for each horse-power."

Belts for driving wood-working machinery require to be wider in proportion to the power required than for metal-working machines; for, on account of their hard and dry surfaces, they possess much less driving power than the latter belts, which are kept soft and pliable by continual contact with the oil.

John Richards, in his practical 'Treatise on Wood Machinery,' says;—

"The belting for circular saws is, as a rule, too narrow, or upon pulleys of too small diameter.

To drive a saw well, and without injurious strain upon the bearings, belts should be one-third the diameter of the saw in width, and the pulley equal in diameter to the width of the belt; which is a very simple rule, and does not give any more than the needed driving force under fair conditions. One-fourth the diameter of the saw to be taken as the diameter of pulleys on cross-cutting spindles. The breadth of the pulley faces to be once and a half the diameter.

" The convexity of pulleys, to keep belts central, should be sufficient for the purpose and no more, as any great degree of convexity interferes with the contact and tends to the destruction of the belt, unless both pulleys have their faces the same, a thing impossible in the case of shifting belts. For pulleys of from 2 to 24 inches face, the convexity should be from one-eighth to one-sixteenth of an inch to the foot, graduated inversely as the width of the faces; for pulleys of narrower face, the convexity may be slightly increased. This is quite sufficient to govern the running of belts, and a necessity for more indicates a fault in the position of the shafting.

" For spindles having unusually high speeds, the writer has found belts of cotton webbing to be preferable. Such belts, if closely woven and of the best material, will, when waxed, be found to have a high tractile power, and to wear well; while their comparatively light weight prevents their lifting from centrifugal force."

The width of a belt varies in direct proportion to the power to be transmitted, and inversely as the speed; and this width should, of course, be calculated for the maximum resistance to be overcome, and not for the average. If the power of a belt 18 inches wide be required, it will generally be found to be much better to put in two 9-inch belts than one so wide; owing to the inequalities in such large pieces of leather, unless they are very carefully selected and prepared, causing great loss of adhesion.

Driving Power of Belts.—The following facts relating to the transmission of power by belts are taken from Box's 'Practical Treatise on Mill Gearing.'

" Let A, Fig. 277, be a pulley fixed so as to be incapable of turning, and T *t* weights suspended by a belt E, which passes round the pulley, and may be caused to embrace it more or less by a small guide-pulley D. Let now the weight T be increased until the friction of the belt is overcome, and it slips on the pulley, the weight T descending.

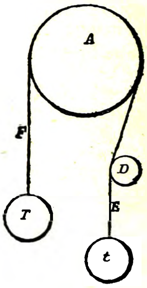
" The ratio between T and *t* varies—

" 1.–With the coefficient of friction of the material of the belt E, sliding on the material of the pulley A. 2.–With the proportion which the arc of the pulley embraced, bears to the whole circumference of the pulley.

" It is independent of the breadth of the belt, so long as T and *t* remain the same, but inasmuch as T and *t*, or the strain on the belt, may increase with the width, this must not be understood to mean that a narrow belt will drive as much as a wide one; for, other things remaining the same, the strain, and therefore the driving power, varies directly and simply as the breadth.

" The ratio between T and *t* is also independent of the diameter of the pulley, other things remaining the same, thus, for instance, a strap which slips on a pulley 1 ft. in diameter, with a weight of 1 cwt. one side, and 2 cwt. at the other, would do the same on a pulley 10 ft. or any other diameter, the surfaces being similar.

277.



" This appears contrary to our instinctive notions, but is quite correct, as proved by experiment. But this must not be understood to mean that a small pulley will carry as much power as a large one, for obviously, if both are set in motion, making the same number of revolutions per minute, the relative speeds of belt would be proportional to the diameters, and the power would vary in the same ratio.

" From Morin's experiments the coefficients of friction are as follows;—

·47 for leather belts in ordinary working order on wooden pulleys.
·28 „ „ „ „ cast iron „
·38 „ „ soft and moist „ „ „
·50 „ cords or ropes of hemp on wooden pulleys.

" It appears from Morin's experiments with cast-iron pulleys, that the driving power is the same, whether they are turned or not, the adhesion of the belt to the polished surface generating as much friction as with a rough surface.

" If we take the case of a belt in ordinary working order on a cast-iron pulley, the coefficient of which is ·28, and calculating for four cases in which the circumference is successively $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and wholly embraced, we find that while $t = 1$ in all cases, T becomes successively 1·553—24·1—3·77 and 5·81.

" The following table is calculated in this way, and gives throughout the value of T when $t = 1$ for different kinds of surface of pulley and states of belt. Decimal parts of circumference of pulley are given instead of vulgar fraction as above.

" When a rope is used, and it is wound more than once round the drum, the frictional power is enormous; thus with a rough wooden pulley, and a rope 2·5 times round it with $t = 1$, T is 2575·3.

" We have so far considered the pulleys as fixed; we will now apply the foregoing facts to the case of pulleys in motion. The mechanical conditions of a driving pulley, with half its circumference embraced by the belt, are shown by Fig. 278, in which we have, as before, the pulley A and the weight T and *t* as in Fig. 277, where we found them to be respectively 1 and 2·41. But in this case the pulley A being free to turn, the weights T and *t* being unequal, there would be no equilibrium without an additional weight at Q, and supposing the drum J to be of the same diameter as the pulley A, it is self-evident that the sum of Q and *t* must be equal to T; therefore $T - t = Q$; or $2{\cdot}41 - 1{\cdot}0 = 1{\cdot}41 = Q$.

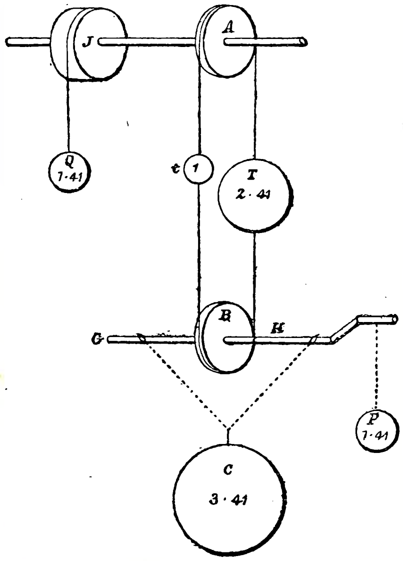
TABLE SHOWING RATIO OF THE STRAINS ON THE BELTS OF DRIVING PULLEYS, Q = T − *t* (BOX).

Ratio of the Arc embraced by the Belt to the entire Circumference.	t.	New Belts on Wooden Pulleys.		Belts in ordinary state on				Soft Belts on Cast-iron Pulleys.		Ropes on Wooden Drums.			
				Wooden Pulleys.		Cast-iron Pulleys.				Rough.		Polished.	
		T.	Q.	T.	Q.	T.	Q.	T.	Q.	T.	Q.	T.	Q.
·2	1	1·87	·87	1·80	·80	1·42	·42	1·61	·61	1·87	·87	1·51	·51
·3	1	2·57	1·57	2·43	1·43	1·69	·69	2·05	1·05	2·57	1·57	1·86	·86
·4	1	3·51	2·51	3·26	2·26	2·02	1·02	2·60	1·60	3·51	2·51	2·29	1·29
·5	1	4·81	3·81	4·38	3·38	2·41	1·41	3·30	2·30	4·81	3·81	2·82	1·82
·6	1	6·59	5·59	5·88	4·88	2·87	1·87	4·19	3·19	6·58	5·58	3·47	2·47
·7	1	9·00	8·00	7·90	6·90	3·43	2·43	5·32	4·32	9·01	8·01	4·27	3·27
·8	1	12·34	11·34	10·62	9·62	4·09	3·09	6·75	5·75	12·34	11·34	5·25	4·25
·9	1	16·90	15·90	14·27	13·27	4·87	3·87	8·57	7·57	16·90	15·90	6·46	5·46
1·0	1	23·14	22·14	19·16	18·16	5·81	4·81	10·89	9·89	23·90	22·90	7·95	6·95
1·5	1									111·31	110·31	22·42	21·42
2·0	1									535·47	534·47	63·23	62·22
2·5	1									2575·30	2574·30	178·52	177·52

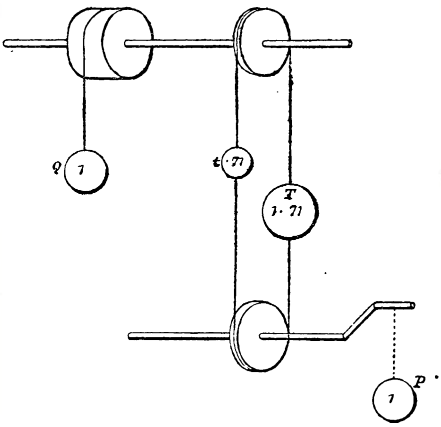
"The mechanical power transmitted by the belt, supposing Q to be raised by a rope coiled around the drum as a hoist or windlass, is the difference between T and *t*, and Q might be increased indefinitely, if we could increase T and *t* indefinitely in the normal proportion; there is, however, a limit to which this can be done, namely, the cohesive strength of the strap by which the heaviest weight T is carried. Where leather is used we can obtain the requisite cohesive strength by increasing the width of the belt, or by making it a double or treble one, and this width must in all cases be proportional to T and not to *t* or Q.

"In Fig. 278 G may represent the engine shaft, H its crank, and P the power which is equal to Q. It will be observed that the weight *c*, or pressure on the bearings due to the tension on the two straps, and also the maximum tension T, is much greater than the power P or the weight Q.

278.



279.



"If the weight Q had been 1·0, the maximum tension T would evidently have been $\frac{2\cdot41}{1\cdot41}=1\cdot71$, and the minimum tension *t* have been $\frac{1\cdot0}{1\cdot41}=\cdot71$, and thus we obtain the strain as shown in Fig. 279; this is the most useful form in which the question can be put, as we thus obtain the proportional maximum strain or width of belt for a unit of power at P.

"With a wooden pulley, the friction of the surfaces is greater, and the strains for the weight Q are different. Here for $t = 1$ we find by the table above that T is 4·38 and hence $Q = 4\cdot38 - 1 = 3\cdot38$. For Q or P = 1 we should have $T = \frac{4\cdot38}{3\cdot38} = 1\cdot29$, and $t = \frac{1}{3\ 38} = \cdot29$; so that with the same power P, a belt 1·29-inch wide, on a wooden pulley, would do as well as one 1·71-inch wide on a cast-iron one.

"In the case of a pulley of cast iron with $\frac{1}{10}$ of the one embraced, the table shows that $T = 1{\cdot}42$, and t being $1{\cdot}0$, Q will be $1{\cdot}42 - 1{\cdot}0 = {\cdot}42$. For $Q = 1$ we have $T = \frac{1{\cdot}42}{{\cdot}42} = 3{\cdot}38$, and $t = \frac{1}{{\cdot}42} = 2{\cdot}38$.

"With a crossed belt on cast-iron pulleys the arc embraced being $\frac{7}{10}$ths of the circumference, we have $T = 3{\cdot}43$, by table $t = 1$, and $Q = 2{\cdot}43$; and hence with $Q = 1$ we obtain $T = \frac{3{\cdot}43}{2{\cdot}43} = 1{\cdot}41$, and $t = \frac{1}{2{\cdot}43} = {\cdot}41$.

"Comparing all the cases presented it will be seen that with the same engine power, the breadth of belt would be in the ratio 1·71, 1·29, 3·38, and 1·41."

The annexed table shows the results of a series of experiments which were made for the purpose of ascertaining the facts governing the transmission of power by means of belts and pulleys. The apparatus used consisted of cast-iron pulleys of 12 and 24 in. in diameter, having slightly rounded and smoothly turned faces, and with their axes fixed in a horizontal position. Over these pulleys belts of various widths were laid, and to their pendant ends certain equal weights were attached; weights were then gradually added to one side until a perceptible motion occurred, when the whole was noted.

Diameter of Pulley.	Material of Belt.	Thickness of Belt.	Width of Belt.	Weight on Platform, including Platform and Parts.	Weight on Hook, including Hook.	Tension of Belt.	Amount of Adhesion.	Proportion existing between Tension and Adhesion.	REMARKS.
inches.		inches.	inches.	inches.	lbs.	lbs.	lbs.		
12	Leather	$\frac{3}{16}$	1	150	50	200	100	2 : 1	The same belt in both cases, old, but good.
24	"	"	1	150	50	200	100	2 : 1	
12	"	"	2	151	50	201	101	2 : 1	Old lathe belt, sticky.
12	"	"	2	300	100	400	200	2 : 1	Old belt, in good order.
24	"	"	2	150	50	200	100	2 : 1	" " "
12	"	"	3	150	50	200	100	2 : 1	" " "
24	"	"	3	300	100	406	206	2 : 1	Results doubtful.
12	Rubber	3-ply	2	190	50	240	140	12 : 7	Old belt, in good order.
24	"	"	2	369	100	469	269	23 : 13	" " "
36	"	"	4	372	100	472	272	59 : 34	" " "

From the above table it will be seen that the adhesion of any open belt is directly as the tension, and not as the surface in contact; for the same results invariably attended the same tension, whether the belt was double the width, or the pulley double the diameter, or both. From this it follows that if we wish to increase the adhesion, or driving power of any belt, without increasing its width, or the strain upon the shafts and journals, we must increase the angle of contact between it and the surface of the pulley. Now the greatest possible angle for an open belt, without a carrier or tightener, is 180°, as upon either the driving or driven pulley this cannot be exceeded; but for crossed, carried, or tightened belts, the angle may be as large as 270°.

The following table gives the power transmitted by belts of various widths, running on pulleys one foot in diameter, at a speed of one revolution a minute, and making various arcs of contact with the pulleys.

Width of Belt.	Arcs of Contact of Belts upon Pulleys corresponding to the Angles.									
	90°.	100°.	110°	120°.	135°	150°.	180°.	210°.	240°.	270°.
inches.	foot-lbs.	foot-lbs.	foot-lbs.	foot-lbs.	foot-lbs.	foot-lbs.	foot-lbs	foot-lbs.	foot-lbs.	foot-lbs.
1	102	109	116	123	132	140	154	165	174	181
2	203	219	233	246	264	280	308	330	348	361
3	305	328	349	369	396	420	462	495	521	542
4	406	437	466	492	528	560	616	660	695	723
5	508	547	582	615	660	701	770	825	869	904
6	609	656	699	738	792	841	924	990	1043	1084
7	711	766	815	861	924	982	1078	1155	1217	1265
8	813	875	932	985	1056	1122	1232	1320	1391	1446
9	914	984	1048	1108	1188	1262	1386	1485	1564	1626
10	1016	1094	1165	1231	1321	1402	1540	1650	1738	1807
11	1118	1203	1282	1354	1454	1543	1694	1815	1912	1990
12	1219	1312	1398	1477	1586	1683	1848	1980	2086	2171
14	1422	1531	1613	1723	1850	1963	2156	2310	2434	2633
16	1626	1759	1864	1970	2114	2244	2464	2640	2781	2894
18	1829	1968	2097	2216	2379	2524	2772	2970	3029	3356
20	2032	2187	2330	2462	2643	2805	3080	3300	3477	3618
24	2438	2624	2796	2954	3161	3366	3696	3960	4171	4342
30	3048	3280	3395	3693	3964	4207	4620	4950	5215	5427

To make use of this table to calculate the driving power of any belt, when the width and angle of contact of the belt, and the diameter and number of revolutions a minute of the pulley are known; find in the table, the number which stands under the given angle of contact and opposite the width of the belt, and this number multiplied by the diameter of the pulley in feet, and the product by the number of revolutions a minute, will give the power transmitted by the belt in foot pounds. For instance, a belt 6 in. wide running over a pulley 3 ft. in diameter at the rate of 200 revolutions a minute, and having an angular contact of 210°; will transmit a force of 990 × 3 × 200 = 594,000 foot-pounds, or 18 horse-power. And a 1-inch belt running on a 1-foot pulley at the rate of 215 revolutions a minute, the angle of contact being 180°, gives about one horse-power.

Comparison of Single and Double Belts.—When it is required to increase the power of any belt, it will generally be found much better to increase its width than the thickness; for with a double belt, the extra tensile strength obtained is counterbalanced by its want of contact with the pulleys, and the extra power required to bend it owing to its want of pliability.

When bent round the circumference of a wheel, the outer parts of the belt are distended, and the inner parts relaxed; and, supposing the section of the belt to be rectangular, the amount of force expended in making these changes will be proportional, directly to its breadth and the square of its thickness, and inversely to the diameter of the wheel. Hence if two belts be of like strength, but the one broad and thin, the other narrow and thick, the amounts of force expended in bending them must be proportional directly to their thicknesses, and hence the advantage of using broad, thin belts.

From these considerations it will be seen that the practice of strengthening belts by riveting, or sewing on, an additional layer must be exceedingly objectionable; indeed, it is difficult to see how any additional strength is gained; for the outer layer must be tight when on the wheel, and slack when free, so that, in reality, the strength of only one layer can be available. The parts of the compound belts are puckered and opened alternately, as evinced by the crackling noise.

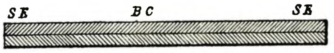
In all places where a high rate of speed is required, single belts will be found to be much more serviceable than double or treble belts; it being much better, for the reasons already pointed out, to increase the width than the thickness, when more power is required. When, however, it is required to transmit great power at a low velocity, double or treble belts may often be employed with great advantage. These belts are generally prepared in the following manner;—The two or three thicknesses of leather are first cemented together, and are afterwards sewn throughout their entire length, either with strong, well-waxed hemp, or with thin strips of hide prepared with alum; the latter being generally employed for this purpose in the North of England, but its advantages over good, waxed hemp are very doubtful.

An improvement on the ordinary double belting has been introduced by Hepburn and Sons, of Southwark, who have given much attention to this branch of leather manufacture. This improvement consists in the use of a corrugated strip of prepared, untanned hide for the outer layer of the belt, and the usual tanned leather for the inner layer; the two being riveted together by machinery. The rivets are made of copper or of malleable iron, and have their ends spread, bent, and driven in flush with the surfaces of the layers. Metallic sewing of this kind is much more durable than ordinary hand sewing; and it has been applied to double belting made entirely of tanned leather with equally good results.

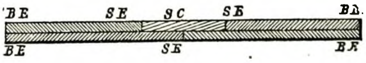
Wide Belts.—The ordinary method of making two or more ply belts is shown in Fig. 280. Pieces of the required width are cut from the centres of the hides, the ends are spliced, and on this one layer others are built up to the required thickness, the lengths in each layer breaking joint, crosswise of the belt, with those below it; the width of each layer being, of course, in one piece. This brings the back centre, or firmest part of the leather, marked B C in the figure, into the centre of the belt, the edges being composed of the side portions of the hide, S E, which are yielding in comparison with the middle.

This method of construction possesses three great disadvantages;—All the pulleys being more or less convex on their faces, and the middle of the belt being firm and not conforming to this convexity, while the edges are of comparatively loose fibre, the consequence is that the edges of the belt will not bind down to the edges of the pulley, and after running a short time they will stretch more than the centre, owing to their loose fibre, and the absence of that lateral support which the central portions have. Thus only a portion of the width of the belt is effective; and, consequently, much less power is transmitted by it than would be the case if the whole of its surface contact were available.

280.



The centre, or tight portion of the belt, having to bear the greater part of the strain, and the other parts not relieving it, it will, as a natural consequence, give out proportionately sooner than it would do if the strain were equalized.



281.

Owing to the shape of the animal, the part of the hide over the backbone often presents a series of full or humpy places, which are of so hard and stubborn a nature that it is very difficult, and often impossible, to work them perfectly flat in the whole hide; and, as a consequence, the belting, when made, possesses a rough, uneven surface along its centre, which prevents it laying flat to the pulleys, and produces a corresponding loss of its adhesion or driving power.

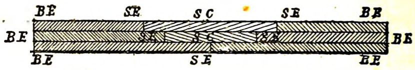
To overcome the above disadvantages, Alexander Brothers have introduced a method of constructing wide belts which they thus describe;—

"In making wide belts, cut the hides along the middle, turn the back edges, B E, outward, and the side edges, S E, inwards, inserting a side centre-piece, S C, so as to break joint widthwise, as shown in Fig. 281.

"In three-ply belts the same method is carried out, in the manner shown in Fig. 282; but there are various other arrangements of the pieces which can be used advantageously in certain cases.

"The edge portions of the belt being of firm, solid, and unyielding leather, and the middle portions of leather of looser fibre and more yielding texture, it is evident that, after running a short time, the middle will give to the higher part of the pulley, and the edges will not only bind down, but will also afford that lateral support which will prevent the middle stretching as much as it otherwise would, and thus giving an even bearing the whole breadth of the belt, and consequently the greatest amount of pulley contact. When the middle of the belt becomes stretched, and allows the edge portions to bed themselves down to the pulley, the working strain will be distributed over the entire width, thus preventing wear on any part alone. Cutting down the middle of the hide enables the currier to work out any uneven or full places, the surplus being cut away in straightening. For belts of 16 to 18 in., or wider, no other plan of making can approach the above arrangement for effectiveness and durability."

282.



As examples of the extent to which the manufacture and employment of large belts is carried in the United States, we introduce the following particulars;—

At the New Jersey Zinc Company's Works, at Newark, N.J., there is a quadruple leather belt of unusually large dimensions. It is 102 ft. long, 4 ft. wide, and weighs 1220 lbs. The outside layer consists of two widths, the second and fourth layers of three widths, and the third layer of four widths, all the layers being riveted and glued together; and the end joints of the pieces forming the several layers are lapped, to give the greatest tensional strength to the whole. This belt runs on an engine-band wheel 24 ft. in diameter, having a straight face of smooth turned iron 4 ft. wide, and over a driven pulley of 7 ft. diameter, situate on the line-shaft, the centre of which lies 5 ft. above the centre of the engine-shaft. This belt has been in use for upwards of three years; and during that time it has given no trouble, even when doing its heaviest work.

A double belt of oak-tanned leather, 186 ft. 6 in. in length, 60 in. wide, and weighing 2212 lbs., was exhibited at the Philadelphia Centennial Exhibition by Hoyt & Co., of New York. This belt was made for the Augustine Mill of Jessup & Moore, paper manufacturers, of Wilmington, Del., and is believed to be capable of transmitting 600 horse-power.

Another belt, exhibited by Jewell & Sons, of Hartford, was described by the manufacturers as the heaviest belt, compared surface for surface, in the exhibition. This belt was 147 ft. 6 in. in length, 36 in. wide, and weighed 1130 lbs., or upwards of 2·57 lbs. a square foot.

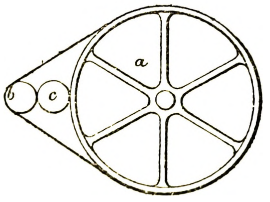
Nearly all the rolling-mills in Pittsburg are driven by belts of 20 in. in breadth and upwards.

Special Arrangements and Methods of Driving by Means of Belts.—When pulleys of very unequal diameters are connected by a belt, the surface contact with the smaller pulley will be so small that the belt will require to be very tightly stretched in order to transmit its full power; and, naturally, the closer the pulleys are together, the more will this be the case. Besides this strain upon the belt, there will also be an extra strain and wear upon the shafts and pulleys, caused by the increased tightness of the belt.

To obviate this strain in the case of their small centrifugal pumps, Gwynne & Co. have adopted the arrangement shown in Fig. 283. In these pumps the power is transmitted from the pulley *a*, on the horse-gear to the riggers *b* of the pump, the relative diameters of the two pulleys being about six to one, and the distance between them only 4 or 5 in. The belt therefore acts on only a very small portion of the rigger, and consequently requires to be very tightly stretched, and so exerts a very heavy strain upon the bearings. To relieve this strain, the friction wheel *c* is placed between the pulley *a* and the rigger *b* in such a position as to touch both in a line connecting their centres. This wheel, revolving freely on its fixed axis, receives the whole of the strain exerted by the belt. The face of this wheel is recessed in its centre so as to bear on the others at the edges only.

To obtain a high speed from a driving belt, without the usual arrangement of counter shafts and belt-pulleys between the main driving-shaft and the machine to be driven, and without the disadvantage of passing the belt over a small pulley, a small grooved pulley, *p*, Fig. 284, is keyed on the shaft to which the high velocity is to be communicated, and upon it is placed a loose inflexible ring, *r*, of two or three times the diameter of the pulley, grooved internally to fit it, and turned up smoothly on the outside to receive the driving belt. The belt gives motion to the speed ring, the inner grooved surface of which communicates a higher speed to the pulley. The speed ring is held in effective driving contact simply by the tension of the belt. For obtaining increased lateral steadiness at very high speeds, a double speed ring may be used if required. By these

283.



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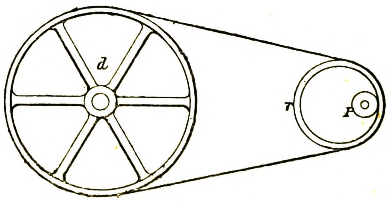

arrangements a belt may be passed over a speed-ring of 16 in. diameter, and yet communicate the same speed to the shaft as if it were passed over a pulley of only 4 in. diameter. Enlarging the diameter of the speed ring will permit the driving pulley *d* to be placed nearer the driven wheel *p* without altering its velocity, and will also increase the adhesion and driving power of the belt.

In Fig. 285 is shown a method of obtaining a high rate of speed, by means of a belt and pulleys, which is known as Parker's patent belting. In this arrangement the axis of the auxiliary pulley B revolves in the ends of the arms E, which are jointed to the arms D at H, the other ends of D turning on the shaft of the pulley A. These levers, E and D, constitute a toggle by means of which the belt F F is forced into contact with the driving pulley A. The endless band F F passes round the pulleys B and C ; but instead of passing round the driver A, as in the ordinary way, it is forced against its periphery only, between the points of contact of the pulley B and C, by means of the toggle E D, as described above. The diameter of the pulley A to that of C may be in the proportion of 30, 40, or even of 50 to 1 ; but the auxiliary pulley B must be of such a diameter as will prevent contact of the belt at G. All of these pulleys must have perfectly straight and smooth surfaces. The belt must be made of well-stretched leather, of perfectly even thickness and texture throughout; and the joints must be permanent, and of the same thickness as the belt. The surface of C may be covered with leather, in order to increase the adhesion between it and the belt. To insure the perfect working of this combination, it is necessary that great care should be exercised, in order that all its parts may be fitted with absolute exactness. This arrangement has been successfully employed for driving small circular saws by hand power.

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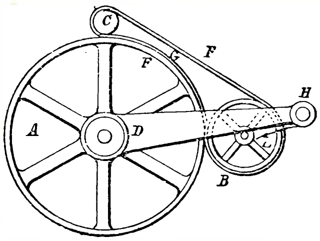

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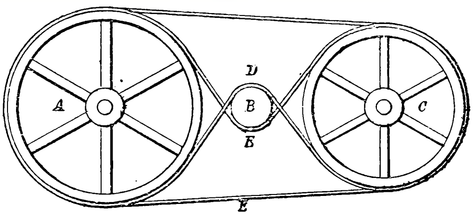

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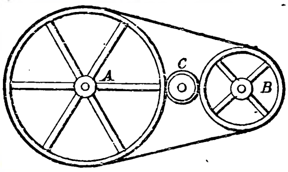

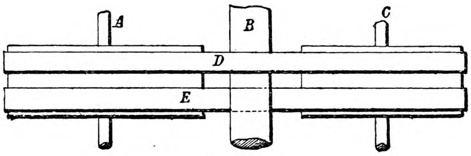

288.

In Fig. 286 is shown Hitchcock's "Traction Gear," for obtaining rapid motion by means of a belt and pulleys. The advantage claimed for this arrangement by its inventor is, that the power is so distributed around the shaft to be driven that the tendency to displace the shaft on one side is counterbalanced by the pressure on the other. It consists, as shown, of three pulleys so placed that the driving pulley A touches the driven pulley C, the two being forced into close contact by means of the auxiliary pulley B, over which the belt is tightly drawn from the pulley A. All of these pulleys should be straight on the face, and have their faces in the same straight line, and their axes in the same plane ; the faces of A and B may be covered with leather. It will be seen, on looking at the figure, that the belt and pulleys A and B all tend to promote rotary motion in the pulley C ; and as the relative diameters of the pulleys A and C may vary greatly, a rapid increase of speed may be produced by this arrangement, while, at the same time, the belt passes freely and with full driving force over comparatively large pulleys, the pulley B being made of any diameter desired.

Another arrangement for obtaining a high speed in a shaft directly from the driving pulley, without the aid of intermediate counter pulleys, and with reduced lateral strain on the bearings of the driven shaft, is known as Weaver's belting. This arrangement is shown in Figs. 287 and 288. A, B, and C are three shafts parallel to each other. A and C carry straight-faced pulleys, upon which run two belts of equal length and width, which are separated in order to prevent contact while running. The lower fold of the belt D is carried over the shaft B, and the upper fold of belt E is carried under B ; and each belt in running imparts motion to the driven shaft in the same direction, while, at the same time, each counterbalances the lateral pressure of the other. A is the driving-shaft and pulley of large diameter ; B the driven shaft of comparatively small diameter ; and C a counter shaft and pulley of any convenient diameter, which is placed in position to carry and return the belts, and which is so arranged that it may be moved to or from B, and fastened at any distance, by screw adjustment or otherwise, so as to secure the proper tension of the belts.

In Fig. 289 is shown a simple means of increasing the driving power of a belt, without altering the size of the pulleys, which has frequently been applied to the driving gear of foot-lathes. An auxiliary pulley, B, is fixed to the lathe-bed in such a manner that it may be moved backwards and forwards, so as to allow of the band being run in grooves of different diameters on A and C, thus altering the speed of C, while that of A remains constant. The position of this auxiliary, or tightening, pulley should be such that the bands, or cords, may be kept from coming in contact at their points of crossing. It will be seen, by referring to the figure, that this arrangement depends for its success upon the well-known fact that the power of any belt, or cord, is, with pulleys whose diameters are in a certain fixed relation to each other, increased in proportion as the surface of the pulley in contact with the belt becomes greater; and it is evident from an inspection of the figure that, by varying the diameter of the pulley B, and by increasing or diminishing its distance from the centres of A and C, a greater or less proportion of the surfaces of these latter pulleys may be brought into contact with the band, the length of the latter being, of course, varied to suit the altered circumstances of the case.

A system which is much in use for transmitting power by means of hempen cords, or round gut belts of small dimensions, is shown in Figs. 290 and 291. It consists of two multigrooved wheels, A and C, which form the driving and driven wheels of the system, into the grooves of which is wound a single endless cord, E, in such a manner that the cord, in leaving the last groove of A, is deflected across and above the other cords, and delivered in a line with the first groove in C, by means of the adjustable single-grooved sheaves B and B'. The bearings of these sheaves are secured to rods, and fixed parallel with the cords, in such a manner that they can be easily slipped to any desired position to take up the slack of the cord. It is evident that with this arrangement the adhesion of the cord, and consequently its driving power, increases in direct proportion to the number of grooves in the pulleys A and C. The grooves in these pulleys should be of an angular, in preference to a circular, section. In Fig. 291 the lowest cord has been accidentally omitted.

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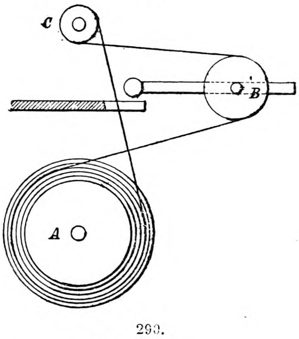

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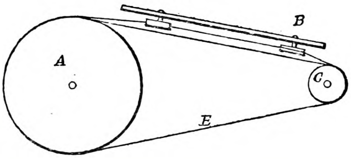

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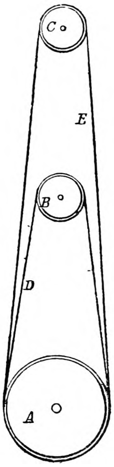

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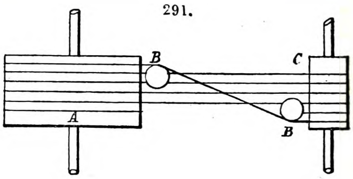

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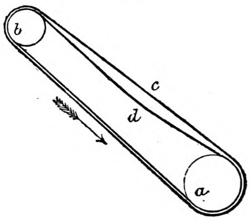


A very simple method of imparting motion to two or more pulleys, situate on different shafts and at different levels, by means of one driving pulley, is shown in Fig. 292. The driving pulley A and the driven pulley B are connected by the belt D in the ordinary manner; over this belt runs a second belt, E, which connects the pulleys A and C. The belts, running on top of each other at A, increase the adhesion sufficiently to drive both B and C. This arrangement will be found convenient, and also economical, for driving lines of shafting situate in different stories from the prime mover below.

The following curious performance of a pair of belts is described by J. S. Lever, of Philadelphia;—"The driving pulley *a*, Fig. 293, on the engine-shaft is 5 ft. in diameter, and runs 75 revolutions a minute. The driven pulley *b* on the line shaft is 3 ft. diameter, and about 20 ft. distant, in a line near 45° with the horizontal. Both pulleys are wooden drums covered with leather, and have sufficient breadth of face for two 12 in. belts. When this arrangement was started, two 12-in. single leather belts were put on side by side, and for some time were run in that way, but never satisfactorily. After many fruitless efforts to obtain a uniform action of the two belts, one accidentally mounted the other, the two running thenceforth as one belt. In this way they drove the line shaft better than ever before. Many experiments were tried in the relative tightness of the two belts, which invariably proved that the best driving was always secured when the inside belt *d* was very slack, sagging, say, 12 to 18 in., and the outside belt *c* quite tight, the working sides, of course, running close to each other, as shown in the figure."

Quarter-Turn Belts.—The following descriptions of the various arrangements for driving by means of the quarter-turn belt are taken from Cooper's treatise on belting, to which we have been indebted for much valuable information;—

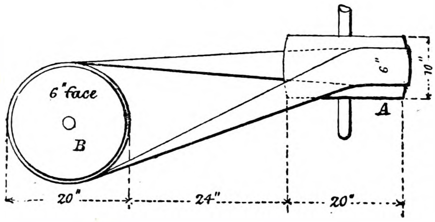
"When two shafts are at, or nearly at, right angles with each other, and not in the same plane, and it is desired to drive one from the other by two pulleys only and a connecting belt, experience has proved that certain conditions are necessary. In the first place, the distance between the near faces of the pulleys must not be less than four times the width of the belt. The pulleys A and B should be so placed that the belt will lead from the face of one to the centre of the face of the other—that is, so that a plane passing through the centre of the face of one pulley will be tangent to that part of the face of the other from which the belt is running.

"In Fig. 294 are shown the position and proper proportions referred to ;—

"The pulley A, from which the belt deflects, should have a wider face than B, in the proportion of 10 to 6, and should be more rounding on the face than is usual; and the pulleys should be as small as may be to do the work, and should be of nearly equal size.

"About 25 per cent. of belt contact is lost when the belt makes a quarter turn, even when the pulleys are of the same size. We have noticed in the performance of a leather belt that the first 90° of lap on the pulley fit closely, as in the ordinary straight belt arrangement; but in the second 90°, about half the width of the belt is forced from contact with the pulley by the strain in the substance of the belt, due chiefly to its imperfect elasticity, and primarily to the oblique deflection of the fold which is leaving the pulley.

294.



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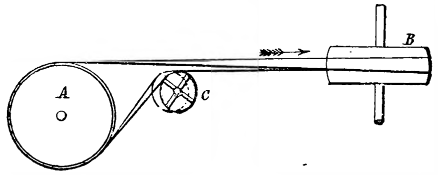

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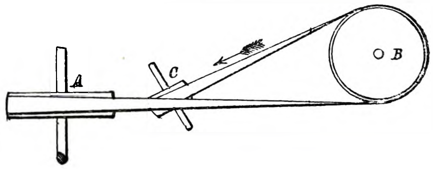

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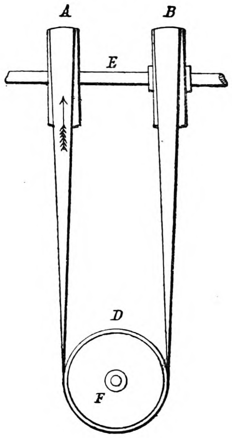

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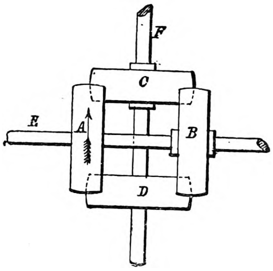

"With a belt perfectly elastic, the same amount of contact, if not more, can be obtained as with an open belt, since the belt would adhere to the face of the pulley up to the line of departure the same in one case as in the other."

In Figs. 295 and 296 is an arrangement of the quarter-twist belt, applied to driving mill-stones or upright shafts, in which the belt runs on three pulleys. "A is the driving pulley on a horizontal shaft; B the driven pulley on a mill-spindle or upright shaft; C the tightener or guide pulley, which is placed at the proper angle for receiving the belt from B and delivering it to A. It has a short shaft, running in bearings secured to a frame which slides vertically in fixed grooves, and may be raised to tighten the belt for driving, or lowered to slacken the belt for stopping, B, at pleasure. B is made wide and straight on the face to admit of motion in raising and lowering the stones, as well as to allow of lead of belt by the different positions of C, which are due to length and tightness of belt. A and C should be rounding on their faces. The figures show the proper positions of the pulleys and shafts, and also give good working proportions, the particulars having been obtained from machinery in use; but the motion of the belt, as shown, should be reversed.

"This arrangement of quarter-twist belt, with intermediate guide pulley, will permit of very short distance between the driving and driven shafts. A case in practice may be cited, in which the driving pulley is 40 in., the driven pulley 18 in., and the guide pulley 16 in. in diameter. All of them are 8-in. face; and the shafts are 4 ft. 7 in. from centre to centre, vertically. This distance might be even less without injury to the belt. In the erection of this arrangement it was found necessary to set the face of the driven pulley 1 in. back of the centre of the face of the driving pulley, and to give the axis of the guide pulley an inclination of 30° to the horizontal line.

"For shafts at right angles but not in the same plane, the belt running on four pulleys. Let E, Figs. 297 and 298, be the driving shaft with tight pulley A, and loose pulley B, and F the *driven* shaft, with tight pulley D, and loose pulley C; all the pulleys of same size, and with rounded faces in the usual way. Let the pulleys be arranged in a square on the plan, whose side is the diameter of pulleys at centre of face, and let an endless belt be put on, as shown, and run in the direction of the arrow. It will be noticed that the loose pulleys C and B run in opposite directions from that of the shafts on which they turn; but since they carry the slack fold of the belt, they are relieved of heavy strain on the shafts. This is a good plan for wide belts when the shafts are a proper distance apart, say ten times the breadth of the belt, and solves the sometimes difficult problem of carrying considerable power around a corner by a belt. There is no loss of contact of the belt on any of the pulleys of this system, and no lateral straining and tearing of the fibres of the belt, as in the usual quarter-twist arrangement, in which only two pulleys are used. The lower shaft may drive the upper one, as well, by changing the direction of motion, or changing the relative positions of the tight and loose pulleys.

"In Figs. 299 and 300, A is the driving pulley on a horizontal main line shaft; B the driven pulley on a mill-spindle or upright shaft: C, a tightener on a shaft parallel to the main shaft, with bearings in a frame, which, with the pulley can be raised or lowered when required to start or stop the pulley B; D, a guide pulley on a verticle shaft running in fixed bearings. The course of the belt is indicated by the arrows. This plan may be resorted to when the pulley A cannot be placed on the main shaft in a position to receive the belt directly from B, as in the case shown in Figs. 295 and 296.

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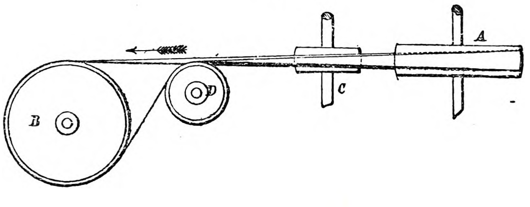

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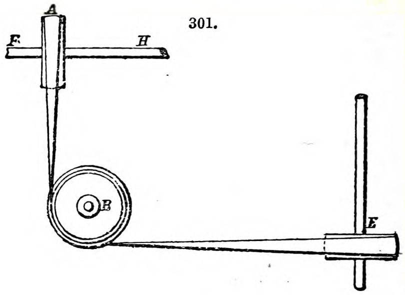

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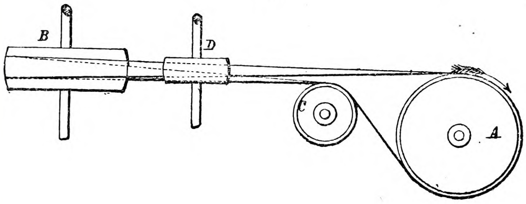

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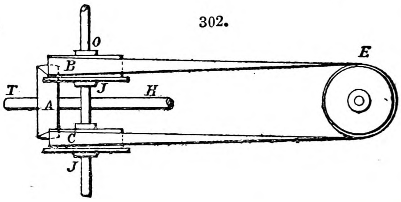

"Figs. 301 and 302 show the usual method of transmitting power to shafts which are at or near right angles with the driver, and Figs. 303 and 304 show an extension of this method to driving two such shafts from one. Let A be the driving pulley on the main shaft, F H; D and E driven pulleys on the counters, at right angles to the main. Place two upright shafts, each with a loose pulley, so that its face will be opposite the middle of the face of A, one to the right and one to the left; over these pass a belt as shown in the cuts. The belt will run either way in both. In Figs. 303 and 304 it will be observed that the driving face of the belt is changed between the two pulleys, D and E, which may be avoided by giving the belt a half twist in this part, which we think, however, would injure the belt more than by using both sides of the same. Collars O and O are placed over the pulleys B and C, and we have added the stationary flanges J and J to the uprights under the pulleys introduced by Wm. Sellers & Co., Philadelphia. This device, whether applied to vertical or horizontal pulleys, is in every way

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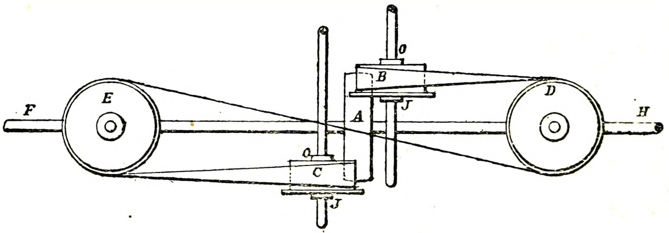

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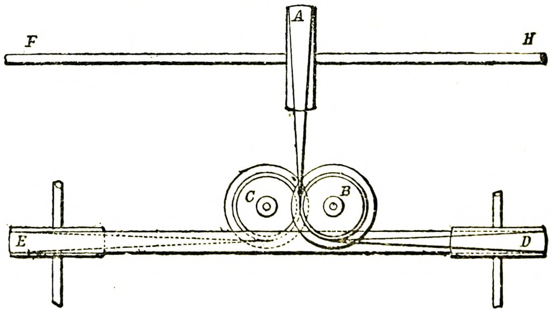

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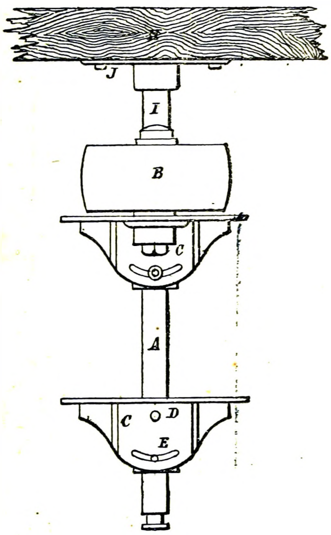
superior to flanges fast to pulleys which tend to lift the edges of the belts and turn them over. On the other hand, when the belts strike stationary flanges, they are thrown back on the pulley faces again, except, perhaps, in the case of soft, flabby belts, which are liable to curl at the edges and roll up.

"What cannot be done with the preceding methods of arranging the quarter-twist belt may be done by the guide pulley devices shown in Figs. 305 and 306, in which the vertical cylindrical staff A is secured by a flange J, and a brace G to an overhead timber A, or other fixture. Upon this staff are placed two hubs F, held by set screws in any position, and each formed with a flat face, to which a flanged bracket C is bolted. The upper bolt D is utilized as an axis, about which the bracket can turn, and the lower bolt E, in a slot, permits the turning, and holds the bracket at the inclination required by the belt. In the centre of each flange C is secured a pin, I, upon which the pulleys B turn. The facility with which these pulleys may have their axes inclined to accommodate the angle of a belt passing from a smaller to a larger pulley, from a higher to a lower shaft, and crossing to the opposite faces of pulleys, favours the employment of this combination, which has an all but universal adjustment, in many places where the previously described arrangements will not serve at all. A case which occurred in practice of belting two shafts, set at right angles, one above the other, having pulleys of different diameters which were to run in opposite directions, and all of them lying close to one another, was disposed of successfully by the use of mechanism exactly like that in Figs. 305 and 306, and this, with that shown in Figs. 301 and 302, are methods employed at the People's Works, Philadelphia, for belt driving around corners, and in confined places.

305.



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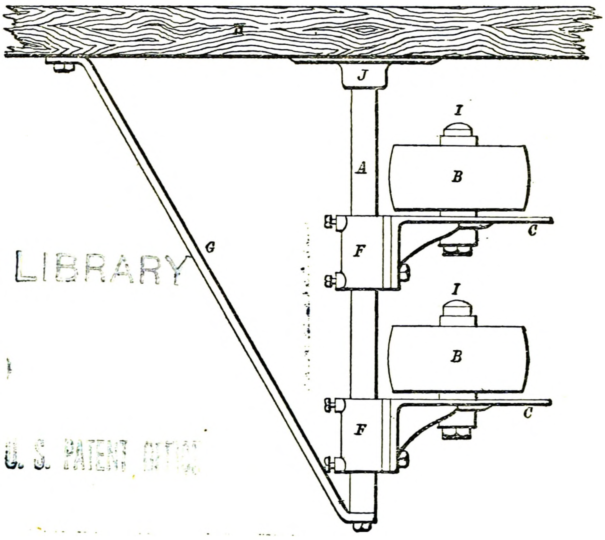

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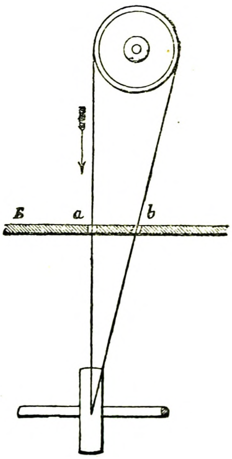
307.



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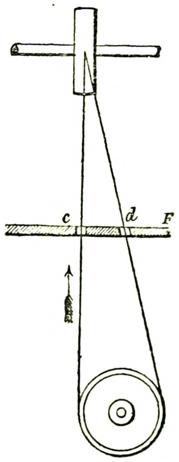


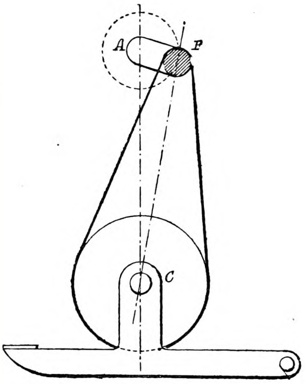
"Two shafts at any angle with each other may be effectively driven by two belts, each having less than a one-eighth twist, and each running on two pulleys, by placing a counter shaft above or below and across the main lines at or near equal angles to the main line shafts."

Holes for Quarter-turn Belt.—"Draw on a level floor, with chalk-line and tram, two full-size views of the pulleys and position of the floor through which belts are to pass; or lay them down on paper to a convenient scale, observing that that fold of the belt which leaves the face of one pulley must approach the centre of the face of the other in a line at right angles to the axis of the latter. Completing the figures as shown in Figs. 307 and 308, the points of intersection *a*, *b*, *c* and *d*, will indicate the places in the floor E F where the centres of both folds of the belt will pass when drawn tightly and at rest. The obliquity of the opening can be best obtained by trial of tape line or narrow belt applied to the pulley face in position, passing through small trial holes in the floor. Allowance in the hole should be made for the sag of slack fold of belt. This is the usual shop method."

37151

Band Links.—Where tension alone and not thrust is to act along a link, it may be flexible, and may consist either of a single band or of an endless band passing round a pair of pulleys which turn round axes traversing and moving with the connected points. For example, in Fig. 309, A is the axis of a rotating shaft, B that of a crank pin, C the other connected point, and B C the line of connection; and the connection is effected by means of an endless band passing round a pulley which is centered upon C, and round the crank-pin itself, which acts as another pulley. The pulleys are, of course, secondary pieces, and the motion of each of them belongs to the subject of aggregate combinations, being compounded of the motion which they have along with the line of connection B C, and of their respective rotations relatively to that line as their line of centres; but the motion of the points *b* and *c* is the same as if *b c* were a rigid link, provided that forces act which keep the band always in a state of tension. This combination is used in order to lessen the friction, as compared with that which takes place between a rigid link and a pair of pins; and the band employed is often of leather, because of its flexibility.

309.



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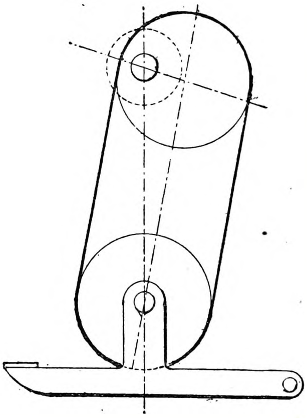
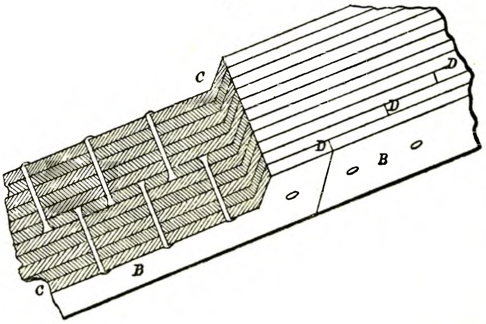


In Fig. 310 is shown a substitute for the arrangement given in Fig. 309; in this an eccentric takes the place of the crank, thus allowing a straight shaft to be used. When the eccentricity equals the radius of the crank, the result is the same, but experiment has proved, in the case of the eccentric used in the treadle arrangement of the latter, that the motion lacks freedom, the treadle moving heavily.

Belt for Cooling Shaft-Journals.—An ingenious and simple method of cooling a journal consists in placing an endless belt of loose, water-absorbing texture on the shaft, as near the heated part as may be, and allowing the lower bight to run in cold water, which may be held in a vessel at a convenient distance below the shaft. Continuous contact of the liquid band carries away the heat of friction as it is produced, without spilling or splattering of water on and about the machinery, and without contact of the lubricant in the journal boxes. This method has been very successfully applied to the shafts of the rolls of calico printing presses.

Varieties of Belting.—Edge-laid Belts.—In Fig. 311 is shown a method of constructing, or building up, a broad, thick belt, which is said to give much better results than wide, thick belting made in the ordinary way by sewing two or more thicknesses together; as it gives a perfectly equal and even texture throughout, and the belt is also alike on both sides. In making this variety of belting, the hide is cut up into strips of the same width as the intended thickness of the belt; and along the centre of these strips, holes about $\frac{1}{8}$ in. in diameter and 1 in. apart are punched. Through these holes wire nails are passed in the manner shown in the figure, their length being rather greater than half the width of the belt. After all the strips have been built upon the nails, the ends of the latter are turned down and driven into the leather; thus making a firm strap without any kind of cement or splicing. When it is required, for any reason, to shorten a strap of this kind, it is only necessary to take it apart at the step line D D of the splice, and after having cut off from each step at one end of the strap the length desired, to join up again with wire nails; which at this part of the strap should be sufficiently long to pass through the whole width.

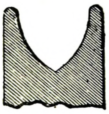
311.



Round Belts.—Round belts cut off less light, occupy less room, make smaller holes in the floors, and require lighter driving pulleys to carry them, and thus save power. In running round belts of cat-gut or hemp the grooves in pulleys should be made with a triangular, or V section, so that the belt touches the pulley in two lines only, tangential to the sides of the groove; in this case the friction of the band, and consequently its driving power, increases in proportion to the decrease of the angle of the groove. The best form of groove is one in which the section corresponds somewhat to the form of a Gothic arch, that is of a triangle with curved sides, as shown in Fig. 312.

Miller's round belts or cords are made by scarfing the edges of a broad belt, and then rolling it up lengthwise, not spirally, but in a horizontal fold, so as to form a perfectly round tube, with a very small central bore; the edges being of course united in a permanent manner. From a number of experiments made with this belting it was proved that the $\frac{1}{4}$-in. round belt is more than equal to a 1-in. flat; and the $\frac{1}{2}$-in. round more than equal to a 3-in. flat. The economy of space and materials, and the diminished friction in shafts and journals, which may thus be obtained by the use of round belts, are points of great importance to the manufacturer.

312.



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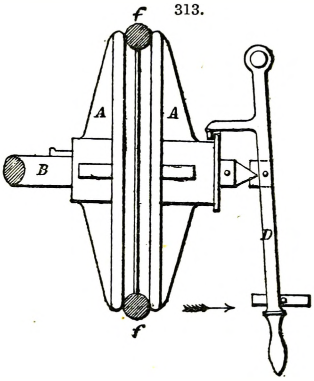

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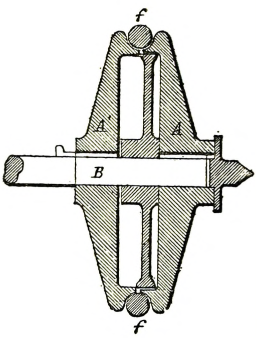
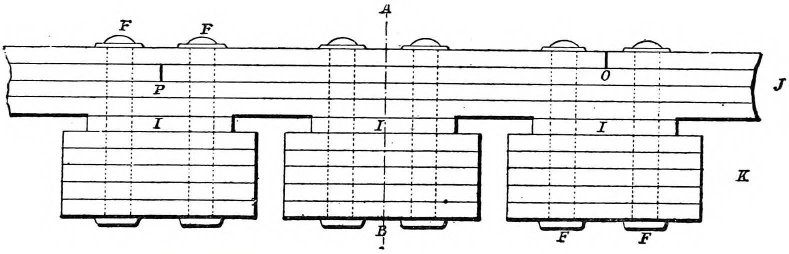


In Figs. 313 and 314 is shown a combined fast and loose pulley for round belts, invented by John Shinn, of Philadelphia. The round belt *f* fits in a groove formed between two half-pulleys, of which A' is fixed and A slides upon a fixed key on the shaft B; between A' and A, and running loosely on the shaft, is a flat-faced pulley C; when A is separated from A' a short distance, the belt *f* will cease to turn them, and will run on and turn C instead. The belt drives the shaft B only when pinched between the half grooves of A' and A. The lever D, when moved in the direction indicated by the arrow, withdraws the half sheave A, and permits the belt to run on the loose pulley. Simple and efficient means for holding the parts together, and drawing one half from the other, are shown in the figures.

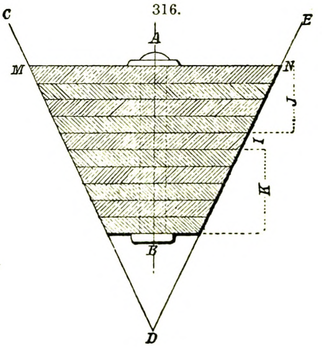
Hoyt & Co.'s Angular Belting.—This consists of a belt of a trapezoidal form, to be used in connection with a **V**-shaped or angular-grooved pulley. The angular belt has a greater surface brought into contact with the pulley than with any other kind. It will wedge itself into the groove and resist any slipping action during the rotation of the pulley, so that the more strain put on one side of the belt the tighter will it be held in the groove; not being liable to slip on the pulley, it may be used very loose, causing less friction, and giving it certainty and regularity of motion. These belts have been used with success when other bands have failed entirely to impart motion to machinery. They are made without a joint in their length; and when the width requires more than one thickness of leather the belt is connected, then riveted or screwed, so that the fastening will not come in contact with the pulley.

315.



Underwood's Angular Belting, Figs. 315 and 316, consists of a number of narrow leather bands, laid a-top of one another, lapping and breaking the joints, in order to secure the greatest combined strength. To the under side of this compound band are fastened short piles of leather, of equal length, forming blocks, each being secured to the band by two iron rivets, as shown in the figures. The four bands J are continuous, the five pieces K and shorter pieces I, interposing, are held together by the rivets F; all are shaped to the angle C D E, which is the correct angle of groove for the wheels. The length of the blocks K is made as short as construction will permit, in order to increase the surface of contact while bending in the groove of the wheels; the pieces I are made shorter to give more flexibility to the band, for which also the blocks are

316.



separated by a narrow space. The elasticity of the leather is sufficient to allow of the necessary bending of the four united bands without injury to the fibre, as it is not intended to use this belt over pulleys of small diameter. The four bands J thus constituting the 'wrapping connector' and tensional strength of this system, while the blocks K form the frictional wedges, so to speak, and the sloping edges of all in the angle of the groove contribute to the great adhesive power possessed by this driving belt. The ends of this belt are joined by bevelling the opposite faces of the part J for 18 in. or 20 in. of its length, and then uniting the whole by bolts having washers and nuts at F, and with heads inside, similar in size and position to the rivets; or the separate strands may be joined, the top one say at O, the next one at P, and in no case having more than one joint between any pair of rivets. 20 in. of this belt, 2½ in. wide, weighs 2 lbs.; 21 in. of the 3-in. belt weighs 3 lbs. The width being measured across M N.

The driving capacity of this kind of belt is evidenced by those used in the N. H. and N. Y. Railroad shops at New Haven, Conn., where a 22-in. double leather belt, weighing 2½ lbs. a square foot, running on pulleys of 6 ft. and 4 ft. diameter, and 16½ ft. distant between centres of pulleys, with a quarter twist, and slipping under a load of 75 to 80 horse-power, with noise that could be heard 1¼ miles away, was replaced by two 2½ in. angular belts, on V-grooved wheels of the same diameters. After sixteen months of running, one of the angle belts was removed; this, of course, put all the work on the remaining one, and this one carried the whole load with apparent ease. Afterwards one-third more work was done by this belt without slipping, visible straining, or injury.

Rubber Belts.—Rubber belts should possess a smooth, polished face; and, as a rule, the brighter the polish of the face of these belts the better will be their working condition. Before starting a rubber belt the dust should be brushed off its face, and if it begin to polish there will not be any trouble with it. In sugar refineries, and in all places where they are subject to the combined influence of heat and moisture, rubber belts are said to answer much better than those made of leather; and also when used as elevators. Generally, however, under the same circumstances, and on the same machines, these bands will not last or wear as long as leather; for, when once they begin to give out, it is next to impossible to repair them. Leather belts, on the other hand, are easily repaired, and when of no further value as belts they can be sold for other purposes. Wide belts cannot be cut up into narrow ones, as leather can be. Neither can they be used for cross or half-cross belts, for shifting belts, cone-pulleys, or for any place where belts are liable to slip, as friction soon destroys them; a few moments of quick motion or friction often causing the gum to roll off the canvas in such quantities as to completely spoil the band. During freezing weather, if moisture find its way into the seams, or between the different layers of canvas composing these bands, and become frozen, the layers will be torn apart and the band spoiled; or if a pulley become frosty the parts of the band in contact with it will be torn off from the canvas and left on the pulley.

The following is a description of the indiarubber belting manufactured by the New York Belting Company, at Newtown, Conn.;—This belting is made of heavy cotton duck, of a uniform and non-elastic character, woven specially for the purpose, with the warp much stronger than the filling; it weighs 2 lbs. per yard, and is cut by machinery into strips of a perfectly regular width. Single strips of this duck will bear a tensile strain of 200 lbs. per inch of width. This belting is vulcanized between layers of a metallic alloy; by which process the stretch is entirely taken out, the surface made perfectly smooth, and the substance thoroughly and evenly vulcanized. It is manufactured by a process by which unusual firmness and solidity are obtained, thereby obviating some objections heretofore urged against indiarubber belting made in the old way. It has a smooth and even surface. It seldom requires tightening more than once. It will always run straight; will stand heat of 300° Fahr. without being affected, and the severest cold will not stiffen it or diminish its pliability; is much stronger than leather, and more durable. It can constantly be run in wet places or exposed to the weather without injury. A 5-ply rubber belt, 12 in. wide, as now manufactured, is considered equal to a double leather belt of the same width.

The comparative adhesion of vulcanized gum and leather belts to the surfaces of pulleys is a question of great interest to manufacturers; and in order to satisfactorily decide the point, a series of experiments were made by J. H. Cheever, the results of which are here given;—

"The apparatus consisted of three equal size iron pulleys, with faces turned in the usual way and secured to a horizontal shaft also fixed. One of these pulleys was used without covering, one was covered with leather, and one with vulcanized gum. In the first set of experiments a leather belt was used of good quality, 3 in. wide and 7 ft. long, with 32 lbs. weight attached to each end, and the belt thus prepared was laid on the iron face pulley. Additional weights were then attached to one end of the belt until it began to slip, which was in this case found to be 48 lbs. When this weighted belt was placed on the leather-covered pulley it required a weight of 64 lbs. to slip it; and when on the gum-covered pulley it required 128 lbs. to slip it. In the second set of experiments, a 3-ply vulcanized-gum belt of the same width, length, and thickness was used, and to each end was attached the same weight as in the other case. To cause this belt to slip on the iron-face pulley required 90 lbs. additional weight; on the leathered-covered pulley, 128 lbs.; and on the vulcanized-gum covered pulley, 183 lbs. In the third set of experiments, the shaft with all the pulleys secured thereto was permitted to turn freely in its bearings. One end of the belt was fastened to the framework of the apparatus, and to the other end was attached a weight of 32 lbs. as before. A rope was wound several times around one of the pulleys, with one end made fast to the rim, and the other allowed to hang freely downwards; to this end weights were attached sufficient to produce rotation of the shaft. The results were the same, requiring in effect the same amount of weight on the end of the rope to rotate the pulleys under the belt as it did on one end of the belt to slip the belt over the pulleys.

"Rubber belts should be cut three-sixteenths of an inch short for every foot of length required. After running, say, for three weeks, take up the slack and they will never again require shortening. To fasten the ends of narrow belts, make two holes in each, put the ends together, and unite by strips of lacing leather in the way usual with leather belts. To secure the ends of wide belts, lap the joint evenly on the outside with a piece of square gum or leather, equal in width to the belt, and rivet, sew, or lace the same firmly to each end of the belt. If belts should slip, from dust or other causes, they should be slightly moistened on the pulley side with boiled linseed oil, making several applications if necessary. Animal oils must never be used, and belts should be protected, while running, from contact with such oils. Should the rubber, from long use or other cause, be worn from the surface of the belt, give it a coat or two of lead paint, containing sufficient japan to dry quickly. For belts which are shifted, put rolls on the shifter bars with axes inclined towards each other at top and bottom, according to circumstances, which has the effect to press the faces of the belts, and relieve the edges from wear. By this plan belts are more easily shifted than by the usual method, and the liability to injure the edges entirely prevented. Use large-headed bolts or rivets for securing elevator buckets."

In rubber belts laced, as shown in Fig. 257, the tearing of the holes began at one-third of the breaking strain. After being subject to a strain of one-fourth, for twenty-four hours, they tore on a slight addition being made to the weight. Under a strain of one-eighth they showed no signs of fracture at the end of a week. Eyeletting the holes brought the standing point up to that of leather belting, the clinching of the metal on the cotton fibre, or filling, reducing the tendency to tear.

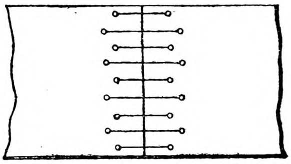
Belting of Intestines.—In America a variety of belting is made from the entrails of sheep, which average some 55 feet in length. They are thoroughly cleaned, and subjected for some days to the action of brine, and are then wound upon bobbins, after which the process is the same as making common rope. If a flat belt is required a loom is employed, and the strands are woven together. A ¾-inch rope thus made will stand a strain of 7 tons, and is guaranteed to last ten years; the best hemp rope of same thickness has a life of about three years.

Paper Belting.—The following is a description of Crane's Paper Belting;—

"The belts are manufactured from pure linen stock, and can be made of any desired thickness, width, and length, but are recommended only for straight and unshifted belts, none being made less than 5 inches wide. They will not stretch nor change shape, and being made all in one piece, of even thickness, will run smoothly and straight. They adhere to the pulleys very closely, and generate no electricity while running. They are quite flexible, and do not crack in passing over pulleys even as small as 6 inches in diameter. They are not affected by heat at ordinary temperatures, nor by dust or oil, but will not run in water; being very tough, they answer for elevator belts, holding the bolts well and running in a direct line without swinging from side to side. Compounds similar to those used for stuffing leather belts, or black lead mixed with sperm oil, are very good to apply to these belts when dry and slipping.

"In lacing narrow paper belts butt the two ends together, and make two rows of holes in each end, as shown in Fig. 317, thus obtaining a double hold, and lace with lacing leather. For wide belts, where extra strength is required, rivet pieces equal in length to width of belt on back of each end, and make the connection with lacing as before. This belting should, in all cases, be put on by the use of clamps, secured firmly to each end of the belt, and drawn together by bolts running parallel with and outside the edge of the belt, making no allowance for stretch. Wide belts, in dry places, can best be connected with Wilson's belt hooks, riveting down the teeth, thus making a connection that will not wear out.

317.



Steel Belts.—The employment of steel belts has been recommended as an experiment worth trying; and the fact that, in the case of a band saw, the power is transmitted by friction on the lower pulley, as high as 15 horse-power being in some cases effectively transmitted by such a saw, is a proof of the entire adaptability of steel to belting purposes. The tensile strength of low steel is such, that it is calculated that a belt of this material, 1 ft. wide and $\frac{1}{16}$ in. thick, could, with a safe working strain, the same in proportion to actual strength as that which is allowed in ordinary belts, transmit 900 horse-power. So far as ability to bear tension is concerned this is certainly enough and to spare.

Cotton Belting.—This is made of the best cotton folded and sewn together, after being saturated with a composition, to prevent the action of the atmosphere affecting the material. A butt joint, as Fig. 317, is most suitable for cotton belting. Oil paint applied to the pulley while running will prevent cotton belts from slipping.

Belts or bands of sheet-iron have already been tried, on several occasions, with very satisfactory results; as an example we quote the following, by John Spiers, of Worcester, Mass.;—

"A lathe used for turning rolling-mill rolls, compound geared, has a 48-in. pulley on it; this is driven by an 18-in. pulley on the counter-shaft, which makes 120 revolutions a minute, and is 8 ft. from the 48-in. pulley, centre to centre. Both pulleys are of iron, with smooth turned faces. A 7-in. double leather belt was used on these pulleys, but would slip when the turning tool became dull. This belt was replaced by one made of Russia sheet-iron, the same as used for stove-pipes and parlour stoves, and was riveted together in the ordinary way; it was 7 in. wide, and was 2 in. longer than the leather belt. This extra length making up for a want of elasticity in the iron. During one year's steady run this iron belt could not be slipped, even when a heavy 'cut' on a 25-in. roll was taken, which broke a 'Sanderson' steel tool having a section of 2 × 2½ in., a cutting surface of 2½ in., a feed of ⅛ in. a revolution, and an overhang of 4 in."

Books on Belting.—Welch (E. J. C.), 'Designing Belt Gearing,' 18mo, 1875. Box (T.), 'Practical Treatise on Mill Gearing,' crown 8vo, 1877. Cooper (T.), 'Treatise on the Use of Belting,' 8vo, 1878.

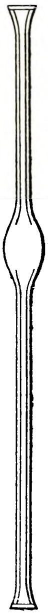
BLASTING.

The operations involved in blasting are very simple. They consist in boring suitable holes in the rock to be dislodged, in inserting a quantity of some explosive compound into the farther end of these holes, in filling up the remaining portion of the holes with suitable material, and in exploding the charge. These operations are known respectively as boring, charging, tamping, and firing.

Before, however, the mode of conducting these operations can be understood from description, it is necessary to have an accurate and a complete knowledge of the nature, form, and construction of the tools, machines, and other appliances used. For though these are all of an exceedingly simple character, they possess features requiring attention. Machine rock-drills will be considered in another article. In the present, attention will be confined to the best methods of applying these drills.

Of the tools used in rock boring, the drill, or borer, is the chief. The form shown in Fig. 318 is that of the common jumper. It consists of a wrought-iron rod terminating at each end in a steeled chisel edge, and having a swell, technically described as the bead, between the extremities to give weight to the tool. The bead divides the jumper into two unequal portions, each of which constitutes a chisel bit, with its shank or stock. The shorter stock is used while the hole is shallow, and the longer one to continue it to a greater depth. With the jumper, the blow is obtained from the direct impact of the falling tool. The mode of using the instrument is to lift it with both hands to a height of about a foot, and then to let it drop. In lifting the jumper care is taken to turn it partially round that the cutting edge may not fall twice in the same place. By this means the edge is made to operate most favourably in chipping away the rock, and the hole is kept fairly circular.

318.



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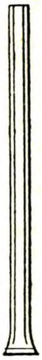

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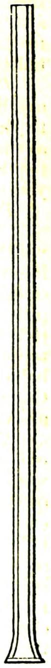
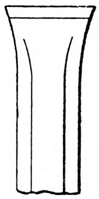


So long as the holes are required to be bored vertically downwards, the jumper is a convenient and very efficient tool; and hence in open quarrying operations it is very commonly employed. In the Welsh slate quarries it is in general use. But in mining the shot holes are more often required to be bored in some other direction, or, as it is termed, at an angle; that is, at an angle with the vertical. Or it may happen that a shot-hole is required to be bored vertically upward. It is apparent that in any one of these directions the jumper is useless. To meet the requirements of such cases, recourse is had to the hammer wherewith to deliver the blow, and the drill is constructed to be used with the hammer. A suitable form of tool for application in this manner is obtained by cutting out the bead of the jumper, and leaving the ends flat for a striking face, as shown in Figs. 319, 320. The form of the two chisels thus obtained is that adopted for the ordinary rock drill.

It will be understood from the foregoing description that a rock drill consists of the chisel edge or bit, the stock, and the striking face. Formerly drills were made, as jumpers are still, of wrought iron, and steeled at each end to form the bit and the striking face. Now they are commonly made of cast steel throughout. The advantages afforded by steel stocks are numerous. The superior solidity of that material renders it capable of transmitting the force of a blow more effectually than iron. Being stronger than the latter material, a smaller diameter of stock, and, consequently, a less weight, are sufficient. This circumstance tends to give greater effect to the blow by diminishing the mass through which it is transmitted. On the other hand, a steel stock is more easily broken than one of iron. Usually the stock is octagonal in section; in length it varies from 20 in. to 42 in. The shorter the stock the more effectively does it transmit the force of the blow; therefore it is made as short as possible. For this reason, several lengths are employed in boring a shot-hole, the shortest being used at the commencement of the hole, a longer one to continue the depth, and a still longer one, sometimes, to complete it. To ensure the free working of the longer drills, the width of the bit is slightly reduced in each length. Also to enable the tool to free itself readily in the bore-hole, and to avoid introducing unnecessary weight into the stock, the bit is made wider than the latter. The difference in width varies from ¼ in. in drills to be used in hard rock, to 1 in. in those to be used in coal. It is evident that the liability to fracture increases with the difference in width. The edge may be straight or slightly curved. The straight edge cuts its way somewhat more freely than the curved; but it is weaker than the latter at the corners, a circumstance that renders it less suitable for very hard rock. Figs. 321 to 323 show the straight and the curved bits, and the angles of the cutting edges. The following proportions are the average adopted for the width of the bit;—

321.



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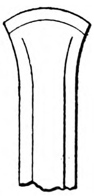

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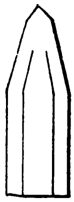


Width of the Bit.	Diameter of the Stock.	Width of the Bit.	Diameter of the Stock.
1 inch.	⅝ inch.	1¾ inch.	1⅛ inch.
1⅛ "	¾ "	2 inches.	1⅜ "
1¼ "	⅞ "	2¼ "	1½ "
1½ "	1 "	2½ "	1⅝ "

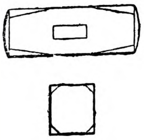
The striking face of the drill should be flat. The diameter of the face is less than that of the stock in all but the smallest sizes, the difference being made by drawing in the striking end. The amount of reduction is greater for the largest diameters; that of the striking face being rarely more than seven-eighths of an inch.

The tempering of drills is a matter requiring careful attention. Upon this the satisfactory progress of the work of excavation often largely depends. The degree of temper is to be determined by the quality of the steel, and by the character of the work to be performed. The larger the proportion of carbon present in the metal the lower must be the temper. The state of the blunted edges, whether battered or fractured, will indicate what degree of hardness it is desirable to produce. The selection of the proper colour is a subject for the exercise of judgment on the part of the smith. Straw colour is generally the most suitable when the boring is in very hard rock, and a light-blue when the rock is only of moderate hardness.

Drills, as we have already said, are used in sets of different lengths. The sets may be intended for use by one man, or by two. In the former case they are described as single-hand sets, and they contain a hammer for striking the drills; in the latter case, the sets are spoken of as double-handed, and they contain a sledge instead of a hammer for striking.

The distinction between a hammer and a sledge is founded upon dimensions only: the hammer, being intended for use in one hand, is made comparatively light, and is furnished with a short handle, while the sledge, being intended for use in both hands, is furnished with a much longer handle, and is made heavier. The striking face of a blasting hammer, or sledge, is made flat, to enable the striker to deliver a direct blow with certainty upon the head of the drill; and to facilitate the directing of the blow, as well as to increase its effect, the mass of metal of which the head is composed is concentrated within a short length. It is well to chamfer or bevel down the edges of the striking face to cause the sledge to fly off from the head of the drill in the case of a false blow being struck, and thereby to prevent it from descending upon the hand of the man who holds the drill. The head of a sledge is of iron; it consists of a pierced central portion called the eye, and two shanks or stumps, the steeled ends of which form the striking faces or panes. The form of the head varies in different localities. A very common one is shown in Figs. 324, 325, and is known as the bully pattern. By increasing the width at the eye, we obtain the broad bully, the former being called, for the sake of distinction, the narrow bully. Another common form is the pointing pattern, shown in Figs. 326, 327. The weight of a sledge head may vary from 5 lb. to 10 lb.; a common and convenient weight is 7 lb. The length of the handle or helve varies from 20 in. to 30 in.; a common length is 24 in. The average weight of hammer heads is about 3 lb., and the average length of the helve 10 in.

324.



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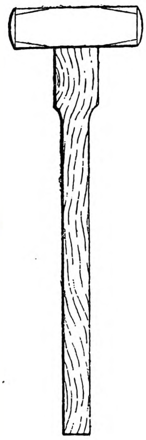

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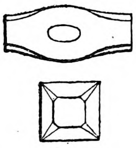

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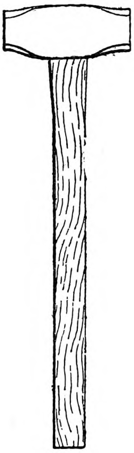
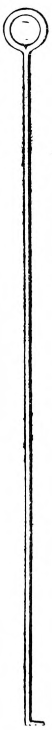


Other tools besides the drill and the hammer are needed in preparing the hole for the charge of explosive. When the bore-hole is inclined downwards, the rock débris or bore-meal made by the drill remains in the bottom of the hole, where it is converted into mud or sludge by the water there present. This sludge has to be removed as the work progresses to keep the rock exposed to the action of the drill. For this purpose a simple tool, called a scraper, is used. It consists of a rod of iron from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. in diameter, and of sufficient length to reach to the bottom of the bore-hole. One end of the rod is flattened out on the anvil, made circular in form, and then turned up a right angle to the stem. The disc thus formed must be less in diameter than the bore-hole, to allow it to pass easily down. When inserted in the hole, the scraper is turned round while it is being pressed to the bottom; on withdrawing the instrument, the sludge is brought up upon the disc. The operation, two or three times repeated, is sufficient to clear the bore-hole. The other end of the scraper is often made to terminate in a ring for convenience in handling, as in Figs. 328, 329. Instead of the ring, however, at one end, a disc may be made at each end, the discs in this case being of different diameters to render the scraper suitable for use in different size bore-holes. Sometimes the scraper is made to terminate in a spiral hook or drag-twist, as it is called. The use of the drag is to thoroughly cleanse the hole before inserting the charge. A wisp of hay is pushed down the hole, and the drag end of the scraper is introduced after it, and turned round till it has become firmly entangled. The withdrawal of the hay by means of the drag wipes the bore-hole clear. Instead of the drag, the loop is frequently employed. This is a loop or eye through which a piece of rag or tow is passed. The rag or tow is used for the same purpose as the hay, namely, to thoroughly cleanse and dry the bore-hole previously to the insertion of the charge.

328.



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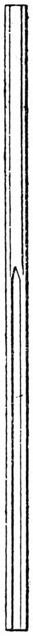


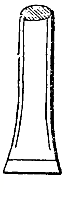
331.

When the bore hole has received its charge of explosive, and the fuse has been laid to the latter, it has to be tamped, that is, the portion above the charge has to be filled up with some suitable substance. For this purpose a tamping iron, rammer, or stemmer, as the instrument is variously called, is required. This instrument is shown in Figs. 330, 331. It consists of metal bar, the tamping end of which is grooved to receive the fuse lying against the side of the bore-hole. The other end is flat, to afford a pressing surface for the hand, or a striking face for the hammer when the latter is needed. To prevent the danger of accidental ignition from sparks caused by the friction of the metal against silicious substances, the use of iron stemmers is prohibited by law. They are usually made of copper, or of phosphor-bronze, the latter substance being more resisting than the former.

Another tool, which should, however, be considered as an extra or auxiliary instrument, rather than as an essential part of a blasting set, is the claying iron or bull. Its use is to force clay into the interstices in the bore hole for the purpose of shutting back the water in very wet ground. It consists of a round bar of iron, called the stock or shaft, a little less in diameter than the bore-hole, and a thicker portion, called the head or pole, terminating in a striking face. The lower end of the shaft is pointed to enable it to penetrate the clay, and the head is pierced by a hole about 1 in. in diameter. Clay in a plastic state having been put into the bore-hole, the bull is inserted and driven down by blows with a sledge. As the shaft forces its way down, the clay is driven into the joints and crevices of the rock on all sides. To withdraw the bull, a bar of iron is put through the eye, and used as a lever to turn it round to loosen it; the rod is then taken in both hands, and the bull lifted out. A slight taper is given to the shaft to allow it to be extracted more easily.

It is desirable to describe here the drills or borer-bits used with machines, since they can hardly be treated of in an article devoted to the consideration of the latter, and their form and dimensions are matters of great practical importance. The dimensions are determined mainly by two conditions, namely, the necessity for sufficient strength in the shank or stock of the tool, and that for sufficient space between the shank and the sides of the hole to allow the rock débris to escape readily. It has been found by experience that these conditions are best fulfilled when the distance between the sides of the hole and the shank of the tool is from $\frac{3}{16}$ in. to $\frac{1}{4}$ in. The form of the cutting edge is determined by several conditions. That first adopted was the chisel edge given to the hand drill. Later, to increase the useful effect of the blow, the edge was doubled, the bit being formed of two chisel edges intersecting each other at right angles. This bit, which from its form was called the cross bit, was found to penetrate the rock more rapidly than the straight or chisel bit. At the commencement of the hole, the gain in speed was very marked; but it diminished gradually as the boring progressed, owing to the difficulty with which the débris escaped. To remedy this defect, the cutting edges were next made to cross each other obliquely, so as to form the letter X. In this way, the two chisel edges were retained, while the breadth of the bit was considerably reduced. This form, described as the X bit, cleared the hole much more effectively than the cross, but not in a manner that was altogether satisfactory. Another modification of the form was therefore made, and this time that of the Z was adopted, the upper and the lower portions of which were arcs of circles, struck from the centre of the bit in the direction contrary to that of the rotation. This form of tool, which is known as the Z bit, readily cleared itself of the rock débris. But besides this advantage, it was found to possess others of an important character. In the chisel-edge forms, the corners of the bit were rapidly worn off by friction against the sides of the bore-hole. In the Z form, this wearing no longer occurred, by reason of the large surface exposed to friction. Another advantage of the Z form lies in its tendency to bore the hole truly circular. Generally, then, it may be stated that this form satisfies most fully the determining conditions. The form of bit, however, that is most suitable in any given case will be determined by particular circumstances. Of these, the nature and the character of the rock will operate most powerfully to influence the choice. Thus the cross bit will generally be found to be the most suitable in fissured rock, while the single chisel edge may be used with advantage in rock of a very solid and hard character. Indeed, on the judicious selection of the most suitable form of cutting edge, the success of machine boring largely depends. The forms of bit described are shown in Figs. 332 to 339. As in the case of hand-boring, each successive length of drill must diminish slightly in the width of its cutting edge; a diminution of about $\frac{1}{32}$ in. may be considered to be sufficient. Care should, however, be taken to ensure the proper dimensions being given to the edge; and to this end, it will be found advantageous to have at hand an accurate gauge, through which the tool may be passed previously to its being fixed to the machine. It is important also that the tool be truly centred; that is, the centres of the edge of the bit, of the shank, and of the piston rod should be perfectly coincident.

332.



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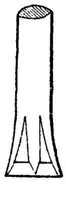

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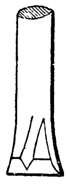

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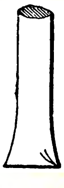

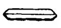

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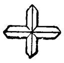

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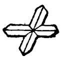

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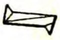


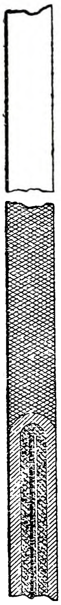
339.

The foregoing descriptions relate to the tools employed in boring the shot-holes. It remains to treat briefly of those appliances which are used in firing the charges, after these have been placed in the holes. The means employed for exploding the charges are of two kinds; in one kind, combustion is made to take place slowly, in order to allow time for the men to make good their retreat from the spot; in the other, the firing material is acted upon at a distance. The former means consists generally of a train of gunpowder, so placed that ignition of the grains must necessarily be gradual and slow. The latter means is electricity acting upon a suitable substance.

The old, and in some parts still employed, mode of constructing a slow train was as follows;— An iron rod of small diameter and terminating in a point, called a pricker, was inserted into the charge, and left in the bore-hole while the tamping was being rammed down. When this operation was complete, the pricker was withdrawn, leaving a hole through the tamping down into the charge. Into this hole a straw, quill, or other like hollow substance, filled with gunpowder was inserted. A piece of slow match, usually touch-paper, affixed to the upper end of this train, served to light it. The combustion of the powder confined in the straw fired the charge, the time allowed by the slow burning of the match being sufficient to enable the man who ignited it to retire to a place of safety.

A far more efficient means of firing is the safety fuse invented by W. Bickford. This fuse, shown full size in Fig. 340, consists of a flexible cord composed of a central core of fine gunpowder, surrounded by hempen yarns twisted up into a tube called the countering. An outer casing is made of different materials, such as tape, thread, or guttapercha, according to the circumstances under which it is intended to be used. A central touch thread, or, in some cases, two threads, passes through the core of the gunpowder. The details of the manufacture have already been given in a former article of this Dictionary. Safety fuse, which in external appearance resembles a piece of plain cord, is fairly certain in its action; it may be used, with equal facility, in holes bored in any direction and is capable of withstanding considerable pressure without receiving injury; it may be used without special means of protection in wet ground, and it may be transported from place to place without risk of damage. In using this fuse, a sufficient length is cut off to reach from the charge to a distance of about 2 in., or further if required, beyond the mouth of the shot-hole. One end is then untwisted a little to loosen the train, and inserted into the charge to a depth of about half an inch. The fuse being held against the sides of the bore-hole with the other end projecting beyond it, the tamping is put in, and the projecting end of the fuse slightly loosened, like the other end. The match is applied directly to this part. The rate of burning is about 30 in. a minute. Safety fuse is usually sold in coils of 24 ft. in length.

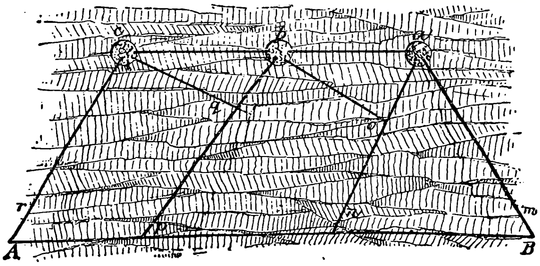
340.



The application of electricity to the ignition of charges in rock blasting offers numerous and very great advantages. These advantages are of two kinds, namely, those due to the simultaneous discharge of the blasts, and those which follow from the nature of the means of ignition. Simultaneous firing lessens the total amount of work to be done by the explosive agents employed. As an illustration, suppose a free rock face A B, Fig. 341, behind which are three shot-holes *a b c*. If *a* be fired first, the lines of fracture will run in the directions *a m*, *a n*, and a wedge-shaped piece, *a m n* will be blown out. The subsequent firing of *b* will cause the lines of fracture to run in the direction *b o*, *b p*, and will force out a trapezoidal block *b o n p*, leaving a boss *a b o*, and the explosion of the shot *c* will subsequently, and in like manner, by causing the lines of fracture *c q*, *c r*, bring out the block *c q p r*, and leave the boss *c b q*. But if these three shots be fired simultaneously, the lines of fracture will run in the directions *a m*, *c r*, *a c*. In this case, the lines of fracture are much shorter than in the preceding; there is, therefore, less work to be done, and consequently a smaller quantity of explosive will be required. Thus there is an advantage on the side of economy obtained from the simultaneous firing, and it is evident that this advantage will increase in importance with the number of shots fired together. But it will be observed that this simultaneous firing leaves no projections or bosses, the face being brought away comparatively clean and smooth. This is another advantage of no small importance. Also by firing the shots at one instant, there is a saving of time, which in many cases may be of some importance.

Of the advantages which follow from the nature of the means of ignition employed, the greatest is, perhaps, the increased safety of those engaged in the blasting operations. The fuses in the several shot holes having been connected together, and put into the circuit formed by the leading and the return wires, the men retire for the blasts to be fired, and the explosion cannot take place until they have withdrawn to the place of refuge provided. With safety fuses it is otherwise. The fuse is ignited in the presence of at least one man, and the burning continues during the time that he is hastening away. Should the fuse, or one portion of it, prove defective and run, as it is termed — that is, burn too rapidly—the chargeman is exposed to great danger; but with the electric fuse, the blast is fired at the precise moment desired, when it has been ascertained that all are under shelter. It will need but little reflection to see that this condition is one which is highly conducive to the safety of those employed. But the majority of accidents in blasting are due to missed shots, or rather to shots that are erroneously supposed to have missed. Not unfrequently the continuity of the gunpowder train in a piece of safety fuse is interrupted, and the burning ceases at that point. But in such a case the covering will smoulder like touch-paper until it has again started the train beyond the point of interruption. The operators, believing the shot to have missed, return to the working face, only to be blown to pieces by the unexpected explosion of the charge. Against this danger electricity affords perfect security, for if a shot fails to explode when the current is sent through the circuit, by no possible chance can it explode afterwards. Thus the advantages on the side of safety are greatly in favour of electrical firing. But there is also a notable gain of speed due to the same cause. From fifteen to twenty minutes are allowed to elapse before the men return to a missed shot. Now, though hang-fires and miss-fires, due to defective manufacture, are not of very frequent occurrence when fuses of good quality are used, miss-fires occasioned by the fuse being severed by the explosion of an adjacent shot are, in close headings and shafts, every-day events. By waiting the prescribed time, much delay is occasioned. This delay is entirely avoided by the use of electricity, for then the missed shot may be approached at once.

341.



When a large body of men are employed, and when speed is a primary requirement, this is an important advantage.

The Austrian chief inspector of railways, Hofrath Ritter von Pischoff, thus expresses himself concerning the advantages of electrical firing;—"A greatly increased amount of work and a notable saving of cost is effected when the shots can be so disposed, and fired as to mutually assist one another. These results are obtained by the use of electricity as the firing agent. The experience which has been gained at the Buchenberg cutting, where the method of firing by electricity has been extensively adopted, has shown that, when properly employed, this means allows, in comparison with the ordinary methods, twice the amount of work to be performed in a given time. It is therefore strongly recommended to adopt electrical blasting whenever it is a question of economy of time and of money."

The requirements of practice may be summarised as follows;—1. Electric fuses should be so constructed as to be easily applicable to the charge of explosive used. 2. They should not be capable of being injured by rough handling. 3. They should be so prepared that the operator may have no trouble or difficulty in putting them into circuit. 4. They should be certain to explode under ordinary conditions of firing. 5. They should explode simultaneously in large numbers.

There are two kinds of electric fuses in use, known respectively as tension and quantity fuses; because the former are fired by means of a current of small quantity but high tension, and the latter are fired by means of a current of large quantity and low tension. In tension fuses, the priming composition is fired by the passage of a current of electricity through it. The circuit is interrupted within the casing of the fuses, and the priming is interposed in the break, Fig. 343. The current, in leaping across the interruption, meets with great resistance from the low conductivity of the substance to be passed through, and consequently heat is generated and the priming fired. To overcome the great resistance occasioned by the break in the metallic circuit, high tension is required in the current, which must therefore be generated by a machine, the low tension current of a battery being insufficient for the purpose. These fuses can, however, be fired by batteries of great power, by reason of the conductivity of the priming composition. In quantity fuses, the priming is fired by the heat generated by the current in a piece of fine platinum wire. This wire is included in the circuit, and surrounded by a substance inflammable at a low temperature, Fig. 342. The heat developed in the wire is due to the great resistance occasioned by its small section. As the circuit is uninterrupted, the low tension current generated by a battery, or by a dynamo-electric machine constructed for quantity may be used. The advantages of high tension lie chiefly in the convenient form and ready action of the machines employed to excite the electricity. Being of small dimensions and weight, simple in construction, and not liable to get quickly out of order, these sources of electricity are particularly suitable for use in mining operations, especially when the operations are entrusted, as they usually are, to men of no scientific knowledge. Moreover, as the means of discharging the machine may be removed until the moment when it is required, this mode of firing offers greater security than the battery. Also by employing a current of high tension, a large number of shots may be fired simultaneously in single circuit, with greater certainty than is obtained with a battery. Another advantage of high tension is the small effect of line resistance upon the current, a consequence of which is that mines may be fired at any distance from the machine, and through iron wire of very small section. The disadvantages of high tensions are the necessity for perfect insulation of the wires, and some degree of uncertainty in the fuse when not properly constructed. When electricity of low tension is employed, the insulation of the wires needs not to be perfect, so that leakages arising from injury to the coating of the wires are not of great importance. In many cases bare wires may be used. Another advantage of low tension is the ability to test the fuse at any moment by means of a weak current, whereby an almost absolute certainty of action may be insured. For this reason it is usually preferred for torpedoes and important submarine work. On the other hand, the copper wires used must be of comparatively large section, and the influence of line resistance is so considerable that only a small number of shots can be fired simultaneously, when the distance is great. Moreover, as the number of fuses is increased, the power of the battery must be augmented by adding to the number of its cells. So that for ordinary mining operations the battery becomes large and unportable. But the chief disadvantage of the battery lies in the fact of its requiring a liquid to excite the current, and the consequent careful attention and delicate handling which the elements require. This defect may, however, be removed to some extent by a suitable form of the battery.

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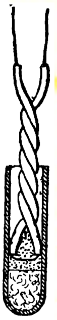

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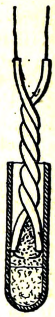


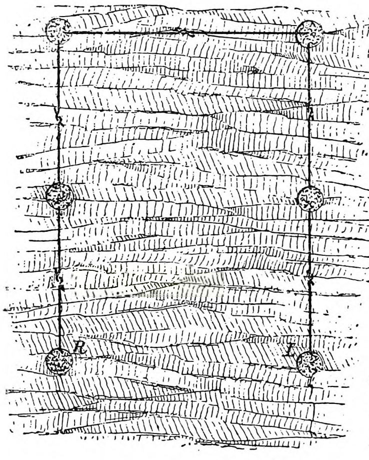
Baron von Ebner, of the Austrian military service, was the first to construct a tension fuse that was at all satisfactory in its action. It did not, however, fully satisfy any one of the requirements enumerated. It was clumsily constructed, and was only fairly certain in its action. But it must be acknowledged to be the model upon which all subsequent inventions have been founded. P. Abel, in England, took Ebner's construction and primed it with a new powder of his own invention. This fuse, known as Abel's fuse, has been largely used for firing guns, and for military purposes generally. But the mode of construction adopted, and the cost of production, have prevented it from being much used in industrial operations. Beardsley, in the United States, introduced a new system, by interposing a bridge of graphite between the terminals within the fuse, the graphite being heated by the passage of the current, and the priming resting upon the graphite thereby fired. This fuse is very certain when fired singly, and it is capable of being tested like a platinum wire fuse, but when connected in large numbers fails.

Several modifications of the foregoing fuses have been adopted in Germany, in the United States, and in England. Some of these, especially those of American invention, fulfil the first four requirements; but none fulfil the fifth. If the number in circuit is not greater than ten, the best of these fuses may be relied upon to explode. But when this number is exceeded some of the fuses miss. The cause of these failures has not been satisfactorily ascertained. If we put two fuses in single circuit, and one of these has much greater conductivity than the other, this one will miss. If they are put in divided circuit, the other one, that is, the fuse which has least conductivity, will miss. If both fuses are practically equal in conductivity, both will explode. From these facts it has been inferred that if all the fuses were equal in conductivity, any number within the power of the machine could be fired at once. The inference, however, is not true. If fuses, made exactly equal in conductivity, are limited in number to fifteen or sixteen, they all explode with certainty, but when the number is greater, failures occur. In searching for the cause of these failures, it would seem that time must be taken into account. The resistance of the fuses retards the current, and possibly the explosion of the first may interrupt the circuit before the current has acted sufficiently on all. It should be remarked here that no better results are obtained by putting the fuses in divided circuit.

To connect the fuses to the machine or the battery, two sets of wires are required when a single shot is to be fired, and three sets may be needed when two or more shots are to be fired simultaneously. Of these several sets of wires, the first consists of those which are attached to the fuses, and which, by reason of their being placed in the shot-hole, are called the shot-hole wires. Two shot-hole wires must be attached to each fuse, and they must be of such a length that, when the fuse has been placed in its proper position in the charge, the ends may project a few inches from the hole. These wires must also be insulated to prevent the escape of the current.

The second set of wires consists of those which are employed to connect the charges one with another, and which, for this reason, are called connecting wires. In connecting the charges in single circuit, the end of one of the shot-hole wires of the first charge is left free, and the other wire is connected, by means of a piece of this connecting wire, to one of the shot-hole wires in the second hole; the other wire in this second hole is then connected, in the same manner, to one of the wires in the third hole; and so on till the last hole is reached, one shot-hole wire of which is left free, as in the first. When frictional machines are used to fire the blasts, the fuses must always be connected up in this manner, which is known as series or single circuit. In this arrangement, shown in Figs. 344 and 345, the whole current is sent through the series of fuses. With magneto-electric machines, it is better to adopt the divided circuit, as shown in Figs. 346 and 347. The leading and the return wires are, in this method, attached to the groups of fuses at L and R, and the current then divides itself, a portion passing through the fuses to the right of L, and another portion through those to the left of that point. Whenever the connecting wires can be kept from touching the rock, and also from coming into contact one with another, in most cases this may be done, bare wire may be used, the cost of which is very small. But when this condition cannot be complied with, and, of course, when blasting in water, the connecting wires, like the shot-hole wires, must be insulated. When guttapercha shot-hole wires are used, it is well to have them sufficiently long to allow the end projecting from one hole to reach that projecting from the next. This renders connecting wire unnecessary, and, moreover, saves one joint for each shot.

344.



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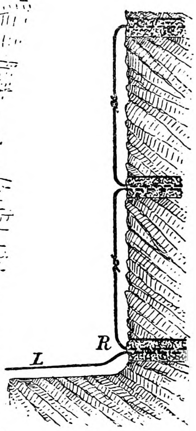

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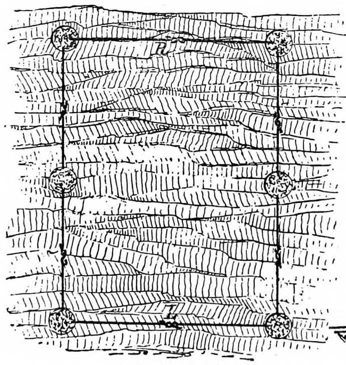

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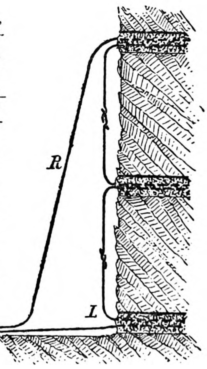

The third set of wires required are those which are used to connect the charges with the machine, or the battery. These wires, which are called cables, consist each of three or more strands of copper wire, well insulated with guttapercha or with indiarubber, the coating of these materials being protected from injury by a sheathing of tape, or of galvanized iron wire underlaid with hemp. Two of these cables are needed to complete the circuit; the one which is attached to the positive terminal of the machine is distinguished as the leading cable, and the other, which is attached to the negative terminal, is described as the return cable. When the cable is provided with a metallic sheathing, the latter may be made to serve instead of a return cable, but is a bad plan.

To fire gun-cotton or dynamite, detonators are used. These are copper capsules about ¼ in. in diameter and 1 in. in length, containing a charge of fulminate of mercury. When safety fuse is used, the end is cut off clean and inserted into the cap, which is then pressed tightly upon the fuse by means of a pair of pliers, as shown in Fig. 348. When the bore-hole is very wet, a little white-lead or grease must be put round the edge of the cap as a protection. The electric fuses are always made water-proof; these are supplied with detonators affixed, as in Fig. 349. When the safety fuse burns down into the cap, or when, in the other case, the priming of the electric fuse is fired, the fulminate explodes, and causes the detonation of the charge in which it is placed.

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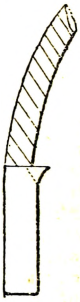

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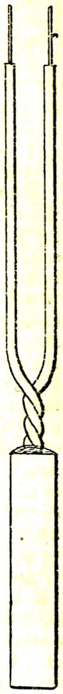
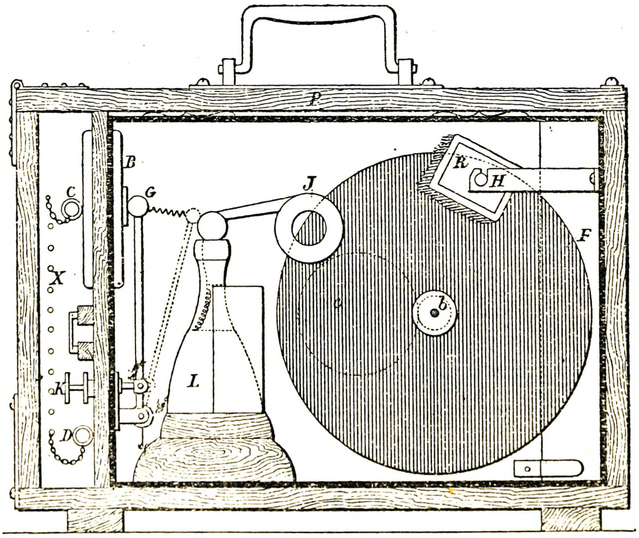


The machines used for firing electrical tension fuses are of two kinds. In one kind, the electricity is excited by friction, and stored in a condenser, to be afterwards discharged by suitable means provided for the purpose. In the other kind, the electricity is excited by the motion of an armature before the poles of a magnet. The former are called frictional-electric exploders, the latter, magneto-electric exploders.

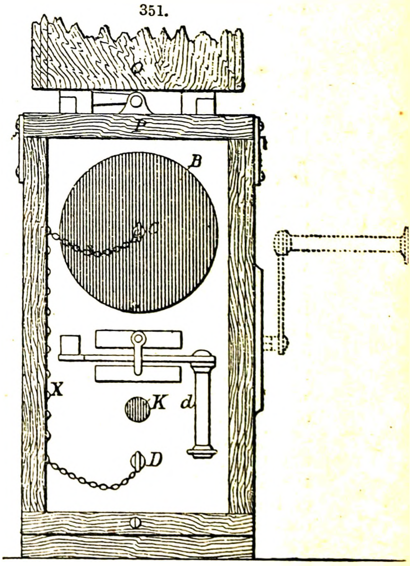
Frictional machines act very well so long as they are kept in a proper state. But as they are injuriously affected by a moist atmosphere, and weaken rapidly with use, by reason of the wearing away of the rubbers, they must be in good electrical condition before using them for firing, otherwise the quantity of electricity excited by a given number of revolutions of the plate will be variable, and vexatious failures will ensue. If, however, the proper precautions be observed very certain and satisfactory results may be obtained. In Germany and in America frictional exploders are generally used. Magneto-electric machines possess the valuable quality of constancy. They are unaffected in any appreciable degree by atmospheric changes, and they are not subject to wear. Moreover, as they give electricity of a lower tension than the friction machine, defects of insulation are less important. Whatever exploder is used it should possess great power. The mistake of using weak machines has done more than anything else to hinder the adoption of electrical firing in Great Britain.

The machine most used in Germany is Bornhardt's frictional exploder, Figs. 350, 351. It is contained in a wooden case 20 in. in length, 7 in. in breadth, and 14 in. in depth, outside measurement. The weight is about 20 lbs. To fire the charges,—F, a plate of vulcanized rubber; J, a collector of the same, and having also a number of metal points; R, cat's-skin rubber; H, its support; L, Leyden jar; G, discharger; B, disc of vulcanized rubber; *c b*, gear-wheels let into the case P,—the leading cable is attached to the upper terminal C, and the return to the lower D, the other ends of these wires being connected to the fuses. The handle *d* is then affixed and turned briskly from fifteen to thirty times, according to the number of fuses in circuit and the state of the machine, to excite the electricity. The knob K is now pressed suddenly in, and the discharge takes place. To allow of the condition of the machine being readily ascertained, a scale of fifteen brass-headed nails X is provided on the outside, which scale may be put in communication with the terminals C and D by means of brass chains, as shown in the figures. If after twelve or fourteen turns the spark leaps the scale when the knob K is pushed in, the machine is in a sufficiently good working condition.

350.

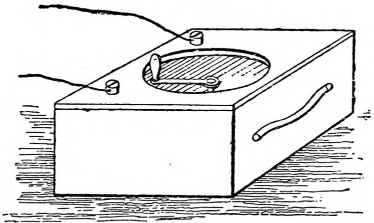


351.

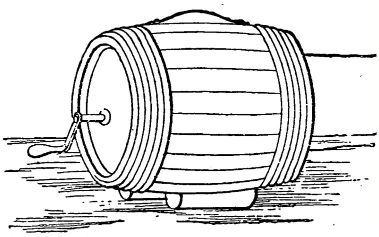


In America there are two frictional exploders in common use. One, Fig. 352, is the invention of H. J. Smith. The other, Fig. 353, is the design of C. Mowbray. The former apparatus is enclosed in a wooden case about 1 ft. square, and 6 in. in depth. The handle is on the top of the case, and is turned horizontally. As in Bornhardt's machine, it is made removable for safety. The cables having been attached to the terminals, the handle is turned forward a certain number of times to excite the electricity, and then turned a quarter of a revolution backward to discharge the condenser, and to fire the blast. By this device, the necessity for a second aperture of communication with the inside is avoided, an important matter in frictional machines, which are so readily affected by moisture. Mowbray's exploder is contained in a wooden barrel-shaped case, and is known as the powder-keg exploder, the form and dimensions of the case being those of a powder keg. The action is similar to that of Smith's machine. The weight is about 26 lbs. All of these machines are extensively used, and good results are obtained from them. They stand well in a damp atmosphere, do not quickly get out of order from the wearing of the rubbers, and are portable.

352.

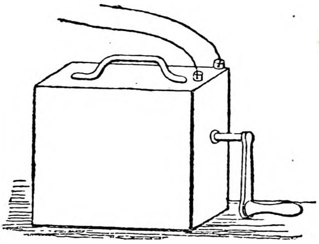


353.



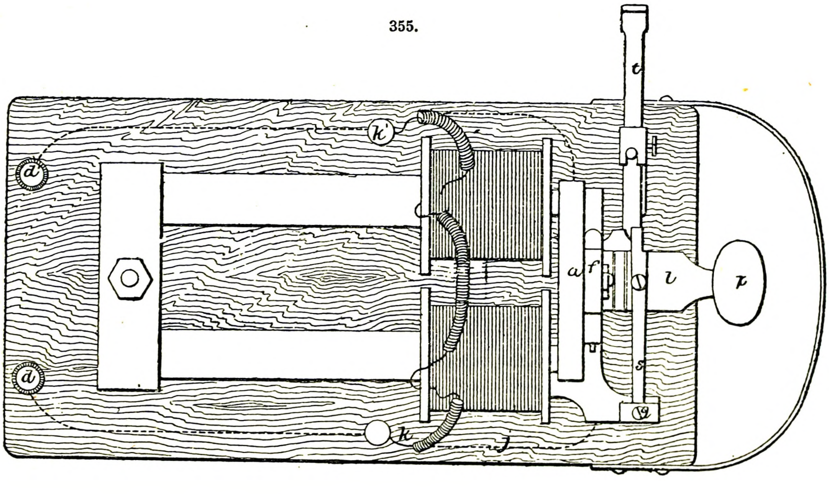
A magneto-electric machine frequently used in England is that of Siemens. This machine is of smaller dimensions than the frictional exploders described; but it greatly exceeds them in weight. The apparatus, shown in Fig. 354, contained within a casing, consists of a Siemens' armature, made to revolve between the poles of an electro-magnet by turning the handle. The coils of the magnet are in circuit with the wire of the armature. The residual magnetism excites weak currents; these increase the magnetism, inducing still stronger currents. The limit is determined by the magnetic saturation of the iron cores of the electro-magnets. By automatic action the current is, at every second turn of the handle, sent into the cables leading to the fuses. To fire with this machine the handle is turned gently till a click is heard, indicating that the handle is in the right position. The cable wires are then attached to the terminals, and the handle is turned quickly but steadily. At the completion of the second revolution the current passes out through the cables and the fuses. As with frictional machines, the handle is, for safety, made removable.

354.



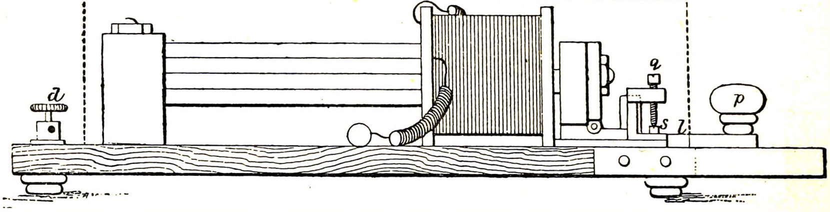
The simplest form of magneto-electric machine in common use is "Breguet's," illustrated in Figs. 355 to 357. It is unsuitable for firing a large number of fuses in divided circuit, but if not more than two or three be required to be fired simultaneously, it will be found convenient. In this machine, the induction coils are placed upon bars of iron constituting a continuation of the arms of the magnet. The latter is fixed upon a base of wood. Against the bars of soft iron, upon which the coils are placed, presses an armature *a*; this armature is fixed upon a lever *l*, which turns about a horizontal axis. When this lever is pressed down by a blow upon the knob *p*, at the end of the lever, the armature is withdrawn from the coils, but remains parallel with them. The lever is provided with a spring *s*, which descends with the lever. While the armature is in contact

355.

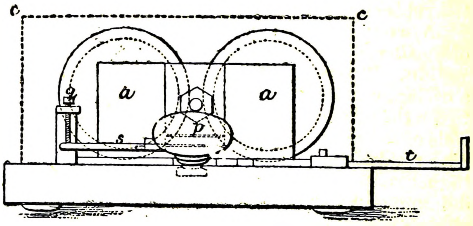


with the coils, the free end of the spring presses against the lower end of the screw q, the support of which is in communication with the wire of the coils. But when the lever is depressed, the spring descends also, until, at a certain point, it is separated from the screw. When this separation takes place, the short circuit $k\,k'$ which previously existed is interrupted, and the current is then forced to pass into the long circuit $k\,d\,d'\,k'$, in which the fuse is placed. The point at which interruption shall take place is regulated by raising or lowering the screw q. This point should be a little above that at which the spring stands when at the end of its stroke, because then the intensity of the current is at its maximum. When the hand is removed from the knob p, a spring beneath the lever, aided by the attraction of the magnet, forces the armature back into contact with the poles. A safety bolt t is pushed under the lever to prevent accidental discharges. The whole of the apparatus, with the exception of the knob and the terminals, is enclosed within a wooden case $c\,c$, shown by the dotted lines.

356.



357.



The leading and the return wires being fixed to the terminals $d\,d'$, and the fuses included in the circuit, the latter are fired by striking a sharp blow upon the knob p.

In concluding this description of the apparatus used in rock blasting, a few remarks are needed on the materials employed as tamping. To tamp a shot-hole is to fill it up above the charge of explosive with some material, which, when so applied, is called the tamping. The use of tamping is to oppose a resistance to the escape of the gases in the direction of the bore-hole. Clay, dried in the sun, or, preferably, by a fire, appears to fulfil most completely the requirements of a tamping material. There being no voids between the particles as in porous substances, there is no passage for the gases. It is usual to prepare the clay beforehand, and this practice is conducive both to rapidity of procedure and to effective results. The former consideration is an important one, inasmuch as the operation, as commonly performed, occupies a good deal of time. To prepare the clay pellets, a lump of the plastic material is taken and rolled between the palms of the hands until it has assumed the form of a sausage, from 3 to 4 in. in length, and of the diameter of the bore-hole. When well dried, these pellets are ready for use. In making them up to the requisite diameter, shrinkage should be allowed for, since it is essential that they fit tightly into the hole. When the charge has been put in and covered with a wad of hay, or a handful of sand or rubbish, one of these pellets is inserted, and pushed home with a wooden rammer. Considerable pressure should be applied to make the clay fill the hole completely, but blows should be avoided. A second pellet is then pushed down in the same manner, and the operations are repeated until the whole of the hole is tamped. To consolidate the mass, light blows may be applied to the outer pellet. It will be found advantageous to place an undried pellet immediately above the charge, because the plasticity of such a pellet enables it to fill all the irregularities of the sides of the hole, and to securely seal the passage between the sides and the tamping. A plastic pellet may, moreover, be pushed down without risk of causing an accidental explosion. In blasting down coal, soft shale is always used for tamping, because it is ready at hand, and heavy shots are not required. In quarries, the dust and chippings of the excavated rock are largely employed as tamping. This material has, however, but little to recommend it for the purpose beyond its readiness to hand. When the hole is inclined downward, dry sand may be very conveniently and effectively used as tamping. But in this case a plastic clay pellet must be first put in immediately above the charge. Without the clay, sand affords but a very weak tamping. Sand tamping may be performed very expeditiously, and it is therefore to be recommended whenever the conditions are not unfavourable to its adoption.

The operations of blasting are begun by striking a few blows with the hammer upon the spot from which the hole is to start, for the purpose of preparing the surface to receive the drill. In some cases, this preliminary operation will not be needed; but generally some preparation is desirable, especially if the surface is smooth, and the hole to be bored at an angle with it. For the purpose of illustration, we will take the case of a hole bored vertically downwards, and will suppose the boring to be carried on by double hand. The surface of the rock having been prepared to receive the drill, one man sits down, and placing the drill between his knees, holds it vertically with both hands. The other man, who stands opposite if possible, then strikes the drill upon the head with the sledge, lightly at first, but more heavily when the tool has fairly entered the rock. The man who holds the drill raises it a little after each blow, and turns it partly round, the degree of turn usually given being about one-eighth of a revolution. By this means, the hole is kept circular, and the cutting edge of the drill is prevented from falling twice in the same place. To keep the tool cool, and to convert the dust and chippings into sludge, the hole is kept partially filled with water, whenever it is inclined downwards. For this reason, downward holes are sometimes described as wet holes, and upward holes as dry holes. The presence of water greatly facilitates the work of boring. It has been found by experience that the rate of boring in a dry and in a wet hole varies as 1 : 1·5; that is, it takes one and a half times as long to bore a dry hole as to bore a wet hole. Then by using water, the time may be reduced by one-third. To prevent the water from spurting out at each stroke, and splashing the man who holds the drill, a kind of leathern washer is placed upon the drill immediately above the hole, or a band of straw is tied round it. When the hole has become too deep for the short drill, the next length is substituted for it, which is in its turn replaced by the third or longest drill as the depth becomes greater. Each drill, on the completion of the length of hole for which it is intended, is sent away to the smithy to be resharpened. In very hard rock, the drills may have to be frequently changed, a circumstance that renders it necessary to have several of the same length at hand.

The depth of shot-holes varies from 1 ft. to 10 ft., according to the nature of the rock, the character of the excavation, and the strength of the explosive to be used. In shafts and in headings, the depth varies generally between 2 ft. 6 in. and 4 ft., a common depth being 3 ft. The débris which accumulates at the bottom of the hole must be removed from time to time, to keep the rock exposed to the edge of the drill. The removal of this sludge is effected by means of the tool called a scraper. If the sludge is in too liquid a state to allow of its ready removal by this means, a few handfuls of dust are thrown in to render the mass more viscous. The importance of keeping the bore-hole free of sludge, and of shortening the time expended in using the scraper has led, in some localities, to the adoption of means for rendering the sludge sufficiently viscous to adhere to the drill. When in this state, the sludge accumulates around the tool rather than beneath it, the fresh portion formed pushing the mass upward till it forms a thick coating upon the drill throughout a length of several inches. When the tool is withdrawn from the hole, this mass of débris is withdrawn with it; in this way, the employment of a scraper is rendered unnecessary. This mode of clearing the bore-holes is commonly adopted by the Hartz miners, who use slaked lime for the purpose. This lime they reduce to the consistency of thick paste by the addition of water, and they store it covered with water, in a small tin box which they carry with them to their work. To use this paste, they take a piece about the size of a walnut, dilute it with water, and pour it into the bore-hole. This lime-paste is, for the purpose intended, very effective in friable rock, especially if it be of a granular structure, as sandstone. As the grains of sand resulting from the trituration of such rocks have no more tendency to adhere to each other than to the drill, each of them becomes coated with a coating of lime, which causes them to agglutinate into a viscous mass, possessing sufficient adhesiveness to enable it to cling to the tool in the manner described. When the hole has been bored to the required depth, it is prepared for the reception of the charge. The sludge is all carefully scraped out to clear the hole and to render it as dry as possible. This is necessary in all cases; but the subsequent operations will be determined by the nature of the explosive, and the manner in which it is to be used. If black powder is employed in a loose state, the hole must be dried. This is done by passing a piece of rag, tow, or a wisp of hay, through the eye of the scraper and forcing it slowly up and down the hole, to absorb the moisture. If water is likely to flow into the hole at the top, a little dam of clay is made round the hole to keep it back. When water finds its way into the hole through crevices, claying by means of the bull must be resorted to. In such cases, however, it is far more economical of time and powder to employ the latter in waterproof cartridges. Indeed, excepting a few cases that occur in quarrying, gunpowder should always be applied in this way. For not only is a notable saving of time effected by avoiding the operations of drying the hole, but the weakening of the charge, occasioned by a large proportion of the grains being in contact with moist rock, is prevented. But besides these advantages, the cartridge offers security from accident, prevents waste, and affords a convenient means of handling the explosive. It may be inserted as easily into upward as into downward holes, and it allows none of the powder to be lost against the sides of the hole, or by spilling outside.

When the hole is ready to receive the explosive, the operations of charging are commenced. If the powder is used loose, the required quantity is poured down the hole, care being taken to prevent the grains from touching and sticking to the sides of the hole. This precaution is important, since not only is the force of the grains so lodged lost, but they might be the cause of a premature explosion. As it is difficult to prevent contact with the sides when the hole is vertical, and impossible when it is inclined, recourse is had to a tin or a copper tube. This tube is rested upon the bottom of the hole, and the powder is poured in at the upper end; when the tube is raised, the powder is left at the bottom of the hole. In horizontal holes, the powder is put in by means of a kind of spoon. In holes that are inclined upwards, loose powder cannot be used. When the powder is used in cartridges, the cartridge is inserted into the hole and pushed to the bottom with a wooden rammer. If the charge is to be fired by means of safety fuse, a piece sufficiently long to project a few inches from the hole is cut off and placed in the hole in the same position as the pricker. When the powder is in cartridges, the end of the fuse is inserted into the cartridge, before the latter is pushed into the bore-hole. The fuse is held in its position during the operation of tamping by a lump of clay placed upon the end which projects from the hole, this end being turned over upon the rock. The tamping is then put in, in small portions at a time, and firmly pressed down with the tamping iron, the latter being so held that the fuse lies in the groove. The tamping should be done with dried clay pellets previously prepared, in the manner described in a preceding paragraph, when the time consumed in tamping will be reduced to a minimum. An abundant supply of such pellets should always be at hand. In downward holes, such as are used in shaft-sinking, the plastic clay pellet and sand may be employed. This tamping may be put in rapidly, and in all but very shallow holes, it is very effective. When it is desired to use sand tamping in horizontal holes, and holes bored in an ascending direction, the sand should be made up in paper cartridges. The tamping employed in the St. Gothard tunnel consisted of sand prepared in this way. At the Mont Cenis tunnel, an argillaceous earth was similarly prepared in paper cartridges for tamping. If the charge is to be fired by electricity, the fuse is inserted into the charge, and the wires are treated in the same way as the safety fuse. When the tamping is completed, the wires are connected for firing in the manner already described. In all cases before tamping a gunpowder charge placed loose in the hole, a wad of tow, hay, turf, or paper, is placed over the powder previously to putting in the tamping. If the powder is in cartridges, a pellet of plastic clay is gently forced down upon the charge. Heavy blows of the tamping iron are to be avoided until five or six inches of tamping have been put in.

When gun-cotton is the explosive agent employed, the wet material which constitutes the charge is put into the shot-hole in cartridges, one after another, until a sufficient quantity has been introduced. Each cartridge must be rammed down tightly with a wooden rammer, to rupture the case and to make the cotton fill the hole completely. A length of safety fuse is then cut off, and one end of it is inserted into a detonator cap. This cap is fixed to the fuse by pressing the open end into firm contact with the latter by means of a pair of nippers constructed for the purpose. The cap, with the fuse attached, is then placed into the central hole of a dry primer, which should be well protected from moisture. When an electric fuse is used, the cap of the fuse is inserted in the same way into the primer. The primer is put into the shot-hole and pushed gently down upon the charge. As both the dry gun-cotton and the detonator may be exploded by a blow, this operation must be performed with caution. Cotton-powder or tonite requires a somewhat different mode of handling. It is made up in a highly compressed state into cartridges, having a small central hole for the reception of the detonator cap. This cap, with the safety fuse attached in the way described, or the cap of the electric fuse, is inserted into the hole, and fixed there by tying up the neck of the cartridge with a piece of copper wire placed round the neck for that purpose. The cartridge is then pushed gently down the shot-hole, or if a heavier charge is required, a cartridge without a detonator is first pushed down, and the primed cartridge put in upon it. No ramming may be resorted to, as the substance is in the dry state. When dynamite is the explosive agent used, a sufficient number of cartridges is inserted into the shot-hole to make up the charge required. Each cartridge should be rammed home with a moderate degree of force to make it fill the hole completely. Provided a wooden rammer be employed, there is no danger to be feared from explosion. A detonator cap is fixed to the end of a piece of safety fuse, and, if water tamping is to be used, grease or whitelead is applied to the junction of the cap with the fuse. A primer, that is, a small cartridge designed to explode the charge, is then opened at one end, and the detonator cap, or the cap of the electric fuse, is pushed into the dynamite to a depth equal to about two-thirds of its length, and the paper covering of the primer is firmly tied to the cap with a string. If the cap is pushed too far into the dynamite, the latter may be fired by the safety fuse, in which case the substance is only burned, not detonated. With an electric fuse this cannot occur. The same result ensues if the cap is not in contact with the dynamite. The object of tying in the cap is to prevent its being pulled out. The primer thus attached to the fuse is then pushed gently down upon the charge in the shot-hole. It should be constantly borne in mind that no ramming may take place after the detonator is inserted. Gun-cotton and tonite require a light tamping. This should consist of plastic clay; or sand may be used in downward holes. The tamping should be merely pushed in, blows being dangerous. A better effect is obtained from dynamite when tamped in this way than when no tamping is used. In downward holes, water is commonly employed as tamping for a dynamite charge, especially in shaft-sinking, when the holes usually tamp themselves. But in other cases, it is a common practice to omit the tamping altogether to save time.

When all the holes bored have been charged, or as many of them as it is desirable to fire at one time, preparation is made for firing them. The charge-men retire, taking with them the tools they have used, and leaving only one of their number who is to fire the shots, in the case of squibs or safety fuse being employed. When this man has clearly ascertained that all are under shelter, he assures himself that his own way of retreat is open. If, for example, he is at the bottom of a shaft, he calls to those above, in order to learn whether they are ready to raise him, and waits till he receives a reply. When this reply has been given, he lights the matches of the squibs, or the ends of the safety fuse, and shouts to be hauled up; or, if in any other situation than a shaft, he retires to a place of safety. Here he awaits the explosion, and carefully counts the reports as they occur. After all the shots have exploded, a short time is allowed for the fumes and the smoke to clear away, and then the workmen return to remove the dislodged rock. If one of the shots has failed to explode, fifteen or twenty minutes must be allowed to elapse before returning to the place. Nine out of ten of the accidents that occur are due to these delayed shots. Some defect in the fuse, or some injury done to it, may cause it to smoulder for a long time, and the blaster, thinking the shot has missed, approaches the fuse to see the effects produced by the shots that have fired. The defective portion of the fuse having burned through, the train again starts, and the explosion takes place, probably with fatal consequences. Thus missed shots are not only a cause of long delays, but are sources of great danger. Accidents may occur also from premature explosion. In this case the fuse is said to run, that is, burn so rapidly that there is not sufficient time for retreat. When the firing is to take place by means of electricity, the man to whom the duty is entrusted connects the wires of the fuses in the manner described at p. 135. He then connects the two outer wires to the cables, and retires from the place. Premature explosion is, in this case, impossible. When he has ascertained that all are under shelter, he goes to the firing machine, and, having attached the cables to the terminals, excites and sends off the electric current. The shots explode simultaneously, so that only one report is heard. But there is no danger to be feared from a misfire, since there can be no smouldering in an electric fuse. The face may, therefore, be approached immediately, so that no delay occurs, and there is no risk of accident. Moreover as all the holes can be fired at the moment when all is in readiness, a considerable saving of time is effected. The workmen on returning to the working face remove the dislodged rock, and break down every block that has been sufficiently loosened. For this purpose, they use wedges and sledges, picks and crowbars. And not until every such block has been removed do they resume the boring for the second blast. Sometimes, to facilitate the removal of the rock dislodged by the shots, iron plates are laid in front of the face in a heading. The rock falling upon these plates is removed as quickly as possible, to allow the boring for the succeeding blast to commence. It is important, in the organization of work of this character, that one gang of men is not kept waiting for the completion of the labour of another.

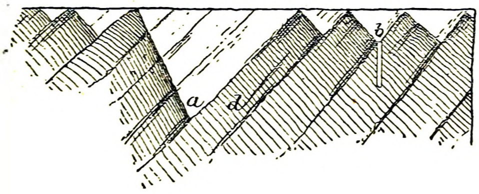
In beginning to blast down a face of rock in underground drivings, the first step is to obtain a free face perpendicular to that of the heading. This is accomplished by boring several holes near together at the centre of the face, and angled so as to bring their ends within only one or two inches apart. These shots are then heavily loaded with explosive, and strongly tamped. When fired, these shots throw out a wedge-shaped mass of rock, leaving a corresponding cavity. In this way, the needed free face is obtained. The operation is described as unkeying the face. Around this cavity other bore-holes are then placed, in such positions, and at such distances, that the explosion of the charges shall blow the rock into the cavity formed by the first shots. In this way, the cavity is enlarged. By placing other shots in the same manner around the enlarged cavity, the whole of the face is brought down. It will be evident that the first shots act under very unfavourable conditions. For this reason, they should consist of heavier charges than those subsequently required, and, whenever practicable, they should be fired simultaneously. The placing of blasting charges affords an opportunity for the exercise of skill on the part of the blaster. As the conditions are constantly varying, no rules generally applicable can be laid down.

The principles upon which rock blasting is conducted will be best understood from the study of some good examples. The following are given as notable instances of drivings intelligently designed and carefully carried out;—

The excavations recently made for the new fortifications at Heiligenberg, in Austria, were executed by the military engineers stationed at that time at Olmütz. These works involved the removal of surface rock and the driving of underground ways. The rock to be removed consisted of alternate beds of sandstone and argillaceous schiste. The surface bed, which was much decomposed by atmospheric agencies, was an argillaceous marl about 5 ft. thick. The beds of schiste dip at an angle of 45 degrees; their thickness varies from a few inches to 6 ft. These beds are traversed by numerous veins of an argillaceous character. The stratification of the sandstone beds is less marked. Cleavage planes, however, exist, along which the rock parted more easily; and a number of veins of loose sand of a maximum thickness of four or five inches. These rocks were of moderate hardness.

The method adopted in the open cuttings consisted, after removing the surface soil to lay bare the rock, in opening a trench parallel to the line of outcrop of the beds at the bottom of this trench, shown in Fig. 358. Shots were placed at *a*, the depth of the bore-holes being made equal to three-fourths the thickness of the bed, and their distance apart twice the thickness. Usually, the shots, which were heavily charged, detached the whole bed; when necessary, their effect was completed by additional shots at *b* from 5 to 6 ft. deep. Whenever a nearly vertical face had to be dealt with, as shown in Fig. 359, the dip of the beds was not taken into account, and bore-holes from 6 to 8 ft. deep were put down, 5 or 6 ft. back from the face. In driving the headings, the method of procedure was varied according to the direction of the heading relatively to the dip of the rock beds. When the direction was that of the strike, a horizontal shot was placed in the thickest bed, as at I in Figs. 360, 361, the depth of the hole being two-thirds that of the thickness

358.



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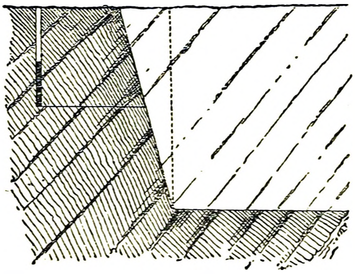

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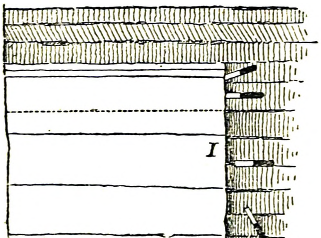
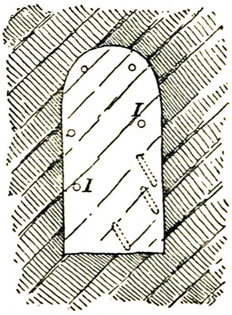
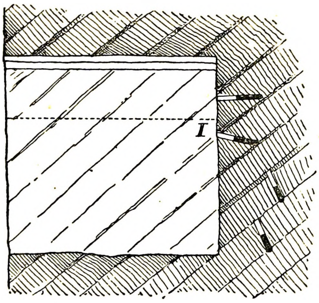


361.

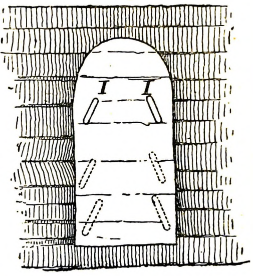


of the bed. After the face had been unkeyed by this shot, other shots placed horizontally were used to bring down the upper portion, the lower portion being subsequently removed by vertical shots. When, on the contrary, the heading was advancing at right angles to the strike, inclined shots were first fired in the middle and lower beds, after which the upper portion was brought down by horizontal shots, as in Figs. 362 to 365. By using dynamite in holes of $\frac{3}{4}$ in. diameter, an average advance of about 2 ft. 6 in. was made in twelve hours. When gunpowder only was used in holes of $1\frac{1}{2}$ in. diameter, somewhat less than half this rate of progress was attained.

362.

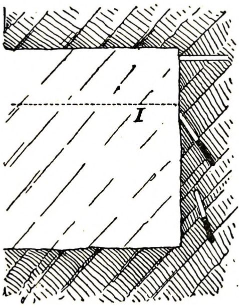


363.

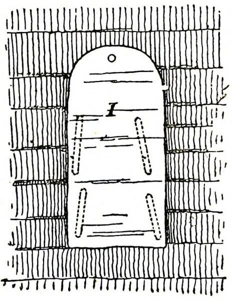


In some cases, the galleries were driven their full width at once; but usually an advance heading was driven, the enlargement being subsequently undertaken. The method of procedure was to drive the heading forward; then to break down the sides, and afterwards to take up the bottom. The several operations, with the direction of the bore-holes, are indicated in Figs. 366 and 367. In taking up the floor, gunpowder was used. The charge of the latter explosive was half the depth of the bore-hole; of dynamite only from one-third to one-fifth of the depth was allowed to the charge. It should also be borne in mind that in the latter case the diameter of the hole was reduced. Plastic clay was used for tamping, and ordinary safety fuse to ignite the charges.

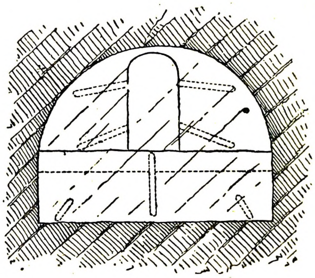
364.



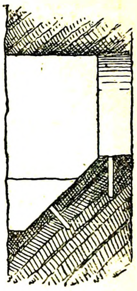
365.



366.



367.

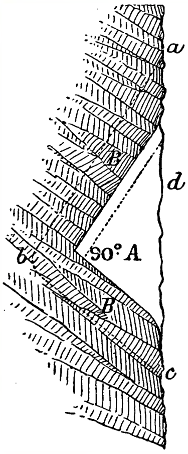


The excavation of the conduit for the Vienna Waterworks affords an excellent illustration of blasting, the work being about 3000 yards in length. The price to be paid was 143 francs per klafter run, a klafter being 1·896 metre; roughly 3*l*. a yard run. The dimensions of the conduit were to be 8 ft. high by 6 ft. wide. The work was carried out in a highly intelligent and strictly scientific manner, a fact that renders this example peculiarly instructive. The explosive used was dynamite of 72 per cent. nitroglycerine, made up into cartridges of $\frac{7}{8}$ in. in diameter. Gunpowder and gun-cotton were first tried, but they were found to be less effective than dynamite in the tough rock through which the conduit had to be driven. Both electric and safety fuses were used.

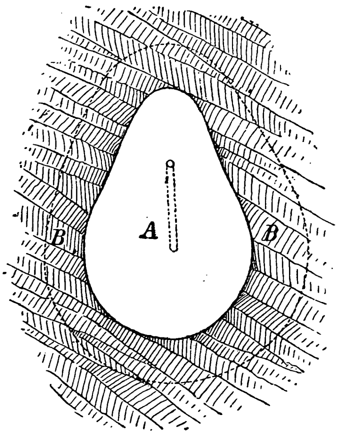
The rock to be passed through was a compact dolomitic limestone, traversed by some longitudinal fractures, and by numerous less important fissures travelling in different directions. The stone was generally more compact in the anticlinal ridges, and more or less fissured in the synclinal depressions; at the bottom of some of the depressions it was sometimes found in the state of conglomerate, and having the appearance of a species of breccia. According as the direction of the heading encountered the plane of fractures more or less perpendicularly, the stone was found to be fissured over a greater or less area. These fractures, which must not be confounded with the veins of spathic limestone found in great quantity in the most compact parts of the rock, and making no difference to the working, were often filled with ferruginous, and sometimes very damp, sand. The hardness and compactness of the rock varied with its purity, and with the quantity of magnesia, spathic limestone, oxide of iron, and similar minerals which it contained.

The operations of blasting differ according as the rock is compact, fissured or conglomerate. Supposing that a plane forebreast, perpendicular to the direction to be followed, is commenced with; the first thing to be done is to select a place for the first shot, which is subject to very unfavourable conditions, because there is only a single free surface, and the shot can only take effect upon the side in which it is placed. The explosion of this first shot forms a cavity, of which the sides form free surfaces, and new planes of less resistance, thus giving a large space for placing the following shots. In the compact rock, it was proved unmistakably, that even when dynamite was used the blast-holes bored in a plane face, perpendicular to the axis of the heading, should have a line of least resistance not in the same direction as the bore-hole, the length of which line should be shorter than the depth of the bore-hole; thus the central shot does not give good effects even when the same hole is charged several times. It is well, therefore, to give the first shot an inclination in conformity with the plane of the forebreast and a depth varying with the compactness and hardness of the stone, the inclination increasing and the depth diminishing in proportion as the hardness increases. With too slight an inclination or too great depth, the effect is considerably diminished; the influence of an error in the depth is less than that of an error in the inclination. Too great an inclination and too little depth are equally undesirable, because the difficulty of boring often increases with the inclination, and also because they lead to the necessity of making too many bore-holes, and expending too much explosive for a given advance of heading. When the depth and inclination of the bore-hole are good, and the charge is correctly proportioned to the depth, the result generally effected in a hard, compact rock is shown in Figs. 368, 369. The effect of the blast is to make the cavity A, and to shatter the part B. The cavity is sensibly limited in its longitudinal section by the lower side of the bore-hole, which usually remains intact, and by a perpendicular line in the direction of the bore-hole, guided by its depth. The sides of the cavity only depart from these directions in the neighbourhood of the free surface. The elevation shows that the blast extends furthest around the bottom of the hole, and that it diminishes as it nears the orifice, around which it is a little increased. The side of the bore-hole remains visible at the farther side of the cavity to a depth varying from $\frac{2}{3}$ to $\frac{3}{4}$ of the hole, measured from the bottom. Fissures are also found, parallel to the hole, penetrating more or less far, according to the hardness of the rock, and the latter may often be broken away with a pick or sledge, in the most favourable cases, as far as the line *a b*, and at other times only to half that distance. When the direction of the bore is good but the depth is too great, and consequently the charge proportioned to that depth is too heavy, the result is that the part C, Fig. 370, is only shattered, and part of the bore-hole remains intact in the rock. When the inclination of the bore is too slight, the effect is still less, the size of the cavity is much diminished, and the greater part of the hole remains intact outside the cavity; the rock is not even shattered to any useful extent, and the sides of the bore are only crushed for 2 or 3 inches, Fig. 371. There is, however, no definite law giving the amount of depth and inclination for a maximum of useful effect, for these quantities depend upon the hardness and compactness of the rock; but it should be admitted as an extreme limit, that a line drawn perpendicular to the direction of the bore from the bottom of the latter should always reach the free surface and be shorter than the bore-hole. In an extremely compact rock which had to be passed through, it was shown by numerous experiments that the depth of the first shot should not be greater than from 15 in. to 20 in., and its line of least resistance 9 in. to 12 in. The charge depends upon the nature of the rock, and upon the depth of the hole. It was given a height equal to $\frac{1}{3}$ of the depth of the hole, for a very compact rock, and was covered with a strong tamping.

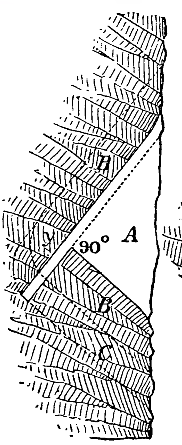
368.



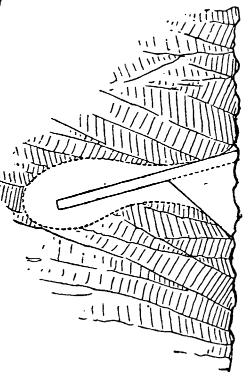
369.



370.



371.

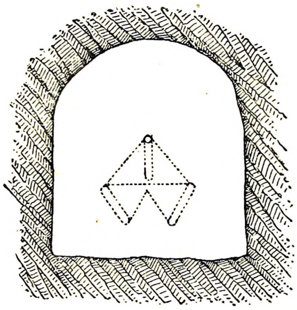


A single shot placed in the forebreast is not generally sufficient to make a wide enough cavity, and it is necessary to fire several of them simultaneously. It was, however, proved that, even in the hardest and most compact parts of the rock, three shots were always sufficient, if well placed and suitably disposed towards the centre of the forebreast, because it is here that the rock is furthest from the sides which span it. In order to ensure the breaking of one cavity into another, which is most favourable to the formation of a wide and deep excavation, care was taken to dispose the shots so that their openings should form an equilateral triangle of about 24 in. in length of side, and to give them a direction so converging that at the bottom they should be only 12 in. to 16 in. apart, Fig. 372. It was found very advantageous to fire the shots simultaneously by electricity. A first cavity of 13 in. in depth being thus obtained, the shots are prepared which are to give the heading its ultimate configuration. They have usually much less inclination and more depth than the previous ones, in the working under consideration they frequently had a depth of 2 ft. 8 in. Here again it is necessary to avoid horizontal shots, and to regulate the depth in such a manner that the bottoms of the bore-holes never descend below that of the existing cavity, because the portions in excess would remain intact. The charge, always varying with the nature of the rock, is determined by the effect of the previous shots; it is not generally more than a quarter of the length of the bore, and never less than one-sixth; a firm tamping is always indispensable to success.

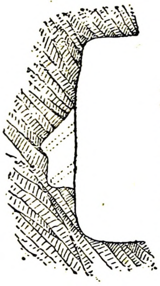
To sum up, in order to make a heading of 6 ft. 3 in. in width and 6 ft. 9 in. in height, in a very hard, compact rock, and where only three men can work at a time, the process is as follows;—

The work is begun by placing in the plane of the forebreast, a little below its centre, the three first shots, and firing them simultaneously. After working with the pick, the cavity I is obtained, Figs. 373 to 375. Eight or ten more holes are then bored in order to break away the part numbered II, situated above and alongside the first cavity. After firing these, three more unkeying shots are placed a little higher than I, so as to give cavity III. After this, the upper portion, IV, is blown down, and subsequently the remaining portion, V, is attacked by eight or ten horizontal or vertical shots placed as deep as possible. Following these instructions, it is possible, with ordinary workmen, to advance the heading by 2 ft. in twenty-four hours, which would require thirty or forty shots, or the consumption of about 7·4lb. of dynamite.

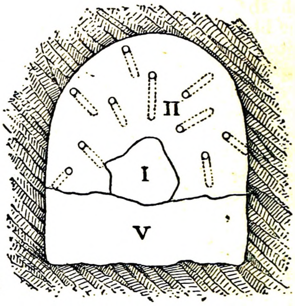
372.



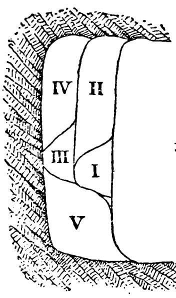
373.



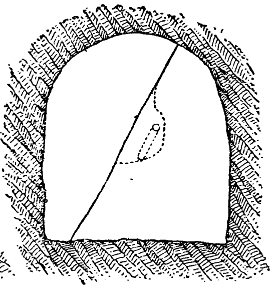
374.



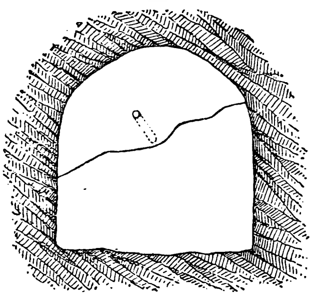
375.



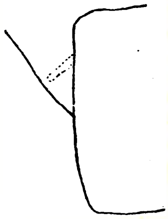
376.



377.



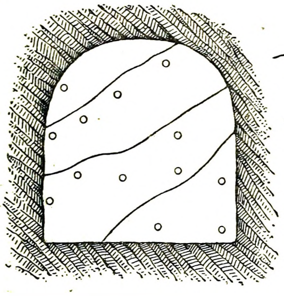
378.



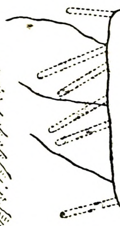
If, instead of being compact, the rock is fissured or stratified, the mode of working is somewhat different. Two cases present themselves; the strata lying longitudinally, as in Fig. 376, or transversely, as in Fig. 377. In the first case, it is advantageous to bore the holes nearly parallel to the plane of stratification, and at intervals apart nearly equal to their depth; the latter, varying with the hardness and compactness of the rock, should not generally exceed 2 ft. in the example quoted. In the second case, Figs. 377, 378, the position to be given to the bore-holes differs according as the plane of the strata is ascending or descending, after leaving the forebreast. When the plane is ascending the holes are all placed above it, and nearly horizontal. On the other hypothesis, they are placed both above and below, and are arranged almost parallel to the plane of stratification, for their force is directed against this plane, which exercises the same influence as a free surface. In the rock to be passed through, the extreme limit of depth, even in this case, was laid down as 2 ft., and much care was taken to avoid cutting into the other strata, so that the remainder of the hole would remain untouched. The method of employing simultaneous firing to accelerate the work, depends much, in a stratified rock, upon the number and respective positions of the strata. When the stratification is regular, as in Figs. 379, 380, it is unnecessary to begin by firing the first three shots which are required in the compact rock to produce a first cavity, and the beds are blown out one after another by a series of shots placed in almost parallel lines. When the stratification is irregular, it is an advantage to begin with a central cavity, which is made at the point where the disposition of the strata is most favourable; in the same way, when the rock is not homogeneous in the forebreast, it is made in the softest and least compact place. The charge is usually less heavy in a stratified rock than in a quite compact one, and its height rarely exceeds one-sixth of the depth of the hole. The work of cutting, under the conditions indicated above, advances at the rate of 2 ft. 8 in. in twenty-four hours, with an average consumption of 6·2 lb. of dynamite.

It is in conglomerate that the effect of the explosion is most considerable, and it extends ordinarily from 2 to 4 in. beyond the bottom of the hole. The rock is much shattered, and work with the wedge rendered very effective. In this case the bore-holes may be inclined much less than in a compact rock, and they may have a depth of 2 ft. 8 in.; the height of the charge may, at the same time, be reduced to one quarter or one-sixth of the length of the hole. When the same material is met with over the whole surface of the forebreast, nothing is gained by beginning the operations with the three first shots mentioned above, and it is possible, without any difficulty, to blow away to a height of 18 in. to 20 in., and to an equal depth, the lower part I, across the whole of the section, Figs. 381, 382. Four or five shots are sufficient for this, placed in the same line, inclined at 35° or 40°, and having a depth of 2 ft., but their lower ends must not reach to within less than 3 or 4 in. of the level of the floor of the heading. The upper part, II, is afterwards broken away to a corresponding depth, the shots being placed in rows, but having less inclination and greater depth. The upper bore-hole is horizontal and placed 2 or 3 in. below the roof. The bore-holes in the lower part receive a charge relatively higher than those of the upper ones, and are fired first. On the contrary when the nature of the rock varies over the surface of the forebreast, and when at the side of the brecciated parts we find compact parts, we begin by taking out a key in the conglomerate before attacking the compact stone. In operating as just described the heading advanced at the rate of 3 ft. 2 in. in every twenty-four hours, with an average consumption of 5·6 lb. of dynamite. In the 'Mémoire de M. Makowicza' tables are given showing, for each of the sixty-eight weeks that the working lasted, an account of the time occupied, the number of blast holes, their depth, the height of the charge in proportion to the depth, the consumption of dynamite and safety fuse, and the corresponding advance of the heading. It will suffice for us to say that in order to cut out 2604 yards of heading, to blow away the rock in the open cuttings, as well as for the removal of rock from a few minor excavations, for the erection of the pumps and the like, 160,074 blast-holes of $\frac{15}{16}$ in. diameter were required, having altogether a length of 79,290 yards; the whole work occupied 434,482 hours, consumed 26,466 lb. of dynamite, and 134,320 yards of Bickford safety fuse. The blasting in open cuttings, carried on near the Kaiserbrunn, required eleven weeks and thirty men, working on an average ten hours a day, to blow away 2676 cubic yards; they bored 4402 blast-holes, having together a length of 2894 yards, and consuming 1180 lb. of dynamite. Some of the holes were made with the jumper and were very deep, electricity being employed to fire the shots.

379.



380.



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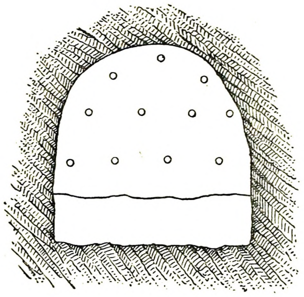
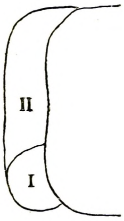


382.



The foreman directed the placing of the bore-holes, their direction and depth. The holes were bored with a drill of 1 inch diameter; in the most compact stone, a miner, working well and able to keep the hole wet, bored 1·05 ft., working downwards and placed at a fair height; boring upwards and in a less convenient spot he could only bore ·8 ft. In a less compact stone the work progressed more quickly, but the length bored in an hour never exceeded 1·3 ft. in the first case and 1 ft. in the second.

Four or five blasts were fired in twenty-four hours. Half-an-hour before each of these, the foreman prepared the charges and the primers. Owing to the cartridges being of the usual lengths, varying from 1 in. to 5 in., it was rarely necessary to cut the cartridges in order to make a charge. A primer was taken, and opened on one side, and, with a small stick, a cavity was made in the dynamite for the detonator; this was fixed to the fuse in the ordinary way, then introduced into the cartridge so that the fuse could not fire the dynamite before the explosion, which would give rise to objectionable gases; the cartridge paper was then turned over the detonator and tied on. To provide for the safety of the men who fired the shots, the fuses were from 2 ft. to 3 ft. 3 in. in length; the length varied between these limits so as to produce the explosion at the most favourable moment. At the time of charging, the hole was cleaned out, and a piece of rag introduced, rolled round the end of a stick. The cartridges, always containing soft dynamite, were then put in, and pressed down with a wooden tamper, sufficiently hard to open the cartridge and permit the dynamite to fill up the hole properly. After this operation a charge of 4 in. in height, in cartridges of $\frac{22}{32}$ in., was reduced to 3½ in. in a hole having $\frac{15}{16}$ in. diameter. The charge thus disposed, the primer was put in its place, without crushing it. It was expressly forbidden to have naked lights in the heading during charging.

The tamping should be effected as carefully and as tightly as possible. Sand is the best; clay and ochreous earth give equally good results. Water-tamping rarely succeeds, and the majority of the shots, so tamped, blow out. This tamping presents also the inconvenience of necessitating the use of an impermeable fuse, which is dearer, and sometimes very difficult to attach to the detonator in such a manner as to keep the water out of it. Better results are obtained with it in blasting in open cuttings, where the borings were deeper and more inclined. This mode of tamping is also defective in headings where the direction of the holes is more or less horizontal. The tamping of ascending holes was difficult to execute, and cost much time; it was facilitated by moistening the earth, or placing it in a casing.

For firing the charge, the ordinary or waterproof Bickford fuse, and sometimes a fuse with a leaden case, are used. The common Bickford fuse gives the best results; it has been noticed that when covered with guttapercha it sometimes gives mis-fires, owing to the melted guttapercha penetrating the detonator, and thus preventing the fire from being communicated to it. The lead-cased fuse possesses the disadvantage of giving rise to fumes of ferrocyanide of lead, which are very noxious. In spite of the advantages presented by electricity, it was not in this instance largely adopted, chiefly on account of the inexperience of the foremen. It was employed with the Abegg primer, as modified by Major von Kocziczka, to unkey the face, and excellent results were obtained by its means.

When all the holes were charged, the end of the fuse was split; planks were laid over the extremity of the air-pipe to protect it from the projected rock splinters, and the workmen then fired the charges by means of portfires of oiled paper. Fifteen or twenty minutes were occupied in charging, tamping, and firing a series of shots. The number of reports were always counted, in order to know whether all the charges had exploded. This being the case, two men hastened to uncover the air-pipe, and to set in motion the fan fixed at the entrance. When the number of reports indicated that some of the shots had missed fire, the foreman, after waiting ten minutes, went alone to the heading to ascertain the cause, and if possible to reprime the charge. Sometimes it was only necessary to relight the fuse, but more often the tamping had to be removed to about 8 in. above the charge, a new primer placed in this space, and the charge re-tamped and fired. Each time that this had to be done, the two charges exploded at the same moment. When the action of the ventilator rendered return to the face possible, the men proceeded with their tools to complete the work begun by the powder, by breaking down the masses which had been displaced, but not completely detached from the rock. The larger portion of the broken rock resulting from the explosion, was found lying in small fragments at the foot of the face of the heading attacked; stones were sometimes thrown to a distance of 40 or 50 paces. To avoid risk of accident, the men working in every part of the heading retired to a safe distance before the explosion.

In America it is the practice in tunnelling to drive headings of the full width at once. By this mode of procedure a more rapid progress is effected, especially when machine drills are used. The method also leads to a notable economy of explosives. The system of wide headings is very favourable to machine labour, and must, therefore, ultimately be generally adopted. The subject is more fully considered under 'Rock-drilling.'

The following table relative to the blasting of one of the headings in the Hoosac tunnel will be found highly instructive, inasmuch as it affords the means of comparison between different systems, and gives important data whereon to ground estimates of other undertakings.

	East Heading.		Heading driven East from West Shaft.
	Nov. 1, 1865, to June 8, 1866. Hand labour and black powder. Area 105 sq. ft.	June 14, 1866, to Nov. 1, 1866. Machine drills with black powder. Area 105 sq. ft.	Nov. 1, 1865, to Nov. 1, 1866. Hand labour with black powder. Area 105 sq. ft.
Days of labour, including foremen	5,476·00	4,350·00	10,101·00
Number of machines sent out	..	979·00	..
Drills dulled	112,489·00	9,336·00	188,505·00
Inches of holes drilled	255,789·00	161,504·00	477,450·00
Number of holes drilled	9,828·00	5,229·00	18,186·00
Pounds of powder used	6,563·00	6,313·00	9,704·00
Feet of fuse	30,202·00	21,951·00	40,896·00
Pounds of candles	2,606·00	2,268·00	3,447·00
Feet of progress made	400·00	191·00	637·00
Cubic yards of rock removed	1,517·00	926·00	2,358·00
Giving for 1 day's labour of 1 man—			
Drilling machines broke down	..	0·255	..
Drills dulled	20·540	2·146	18·662
Inches of holes drilled	46·703	37·123	44·298
Number of holes drilled	1·795	1·204	1·800
Pounds of powder used	1·198	1·451	0·961
Feet of fuse used	5·515	5·046	4·049
Pounds of candles used	0·476	0·521	0·342
Feet of progress made	0·073	0·044	0·063
Cubic yards of rock removed	0·277	0·213	0·233

	East Heading.		Heading driven East from West Shaft.
	Nov. 1, 1865, to June 8, 1866. Hand labour and black powder. Area 105 sq. ft.	June 14, 1866, to Nov. 1, 1866. Machine drills with black powder. Area 105 sq. ft.	Nov. 1, 1865, to Nov. 1, 1866. Hand labour with black powder. Area 105 sq. ft.
On 1 ft. of advancement required—			
Number of drilling machines working until broken	..	22·718	..
Day's labour of 1 man	13·674	5·112	15·865
Drills dulled	280·871	48·752	296·066
Inches of holes	638·624	843·363	702·764
Number of holes	24·539	27·305	28·563
Pounds of powder	16·387	32·966	15·241
Feet of fuse	75·410	114·626	64·231
Pounds of candles	6·506	12·842	5·514
Cubic yards of rock removed	3·788	4·834	3·703
Average depth of holes in inches	26·025	30·886	24·604
Depth of holes in inches cut by each single drill	2·274	17·299	2·374
Pounds of powder consumed in each hole ..	0·668	1·207	0·533
Feet of fuse used for each hole	3·073	4·178	2·249
Depth of holes cut by each drilling machine ..	..	164·968	..
Number of holes cut by each drilling machine	..	5·341	..
	Holes, $1\frac{3}{8}$ inch diameter.	Holes, $1\frac{5}{8}$ to $1\frac{6}{8}$ inch diameter.	Holes, $1\frac{3}{8}$ inch diameter.

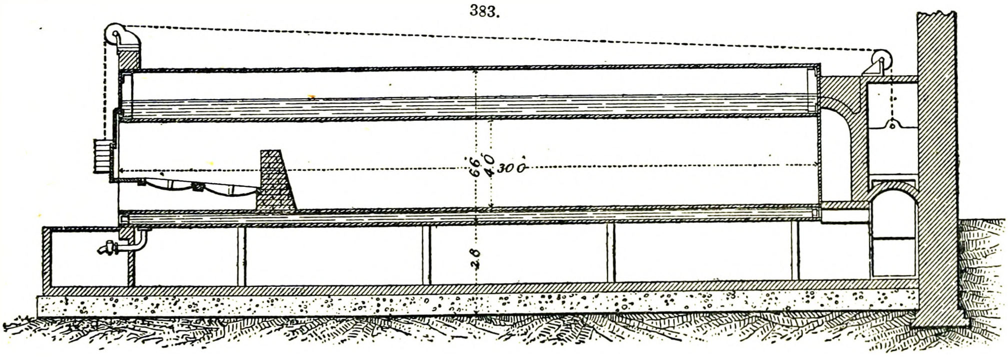
Books on Blasting.—André (G. G.), 'Rock Blasting,' 8vo, 1878; 'Practical Treatise on Coal Mining,' 2 vols., 4to, 1876. Drinker (H. S.), 'Tunnelling, Explosive Compounds, and Rock Drills,' 4to, 1878. Spon (Ernest), 'The Modern Practice of Well-Sinking and Boring,' crown 8vo, 1875.

BOILERS.

The economical production of steam is one of the most involved of problems and consequently steam boiler design is a matter as varied as can be. It is not our purpose here to treat it exhaustively, but to illustrate some of the best forms of construction, which have been practically tested and produced favourable results. Boilers are designated by names indicating their construction, shape, position, use, or locality in which they are extensively made, and frequently by the name of the inventor.

A pair of ordinary Cornish boilers, as they are constructed and set in the English county from which they derive their name, is shown by Figs. 383 to 385. Each has the following dimensions; diameter 6 ft. 6 in., diameter of furnace tube 4 ft. 2 in., thickness of shell $\frac{7}{16}$ in., thickness of tube $\frac{1}{2}$ in., length of boiler 30 ft., weight 10 tons. The ends are stayed by means of gusset stays formed of $\frac{7}{16}$ in. plate and double angle irons. The furnace tubes are often strengthened by means of angle or T iron rings, this is desirable although not adopted in the examples, Figs. 383 to 385. The furnace gases are made to pass from the tube by splitting the draught along the sides; they then meet under the boiler in the bottom flue, and thence to the chimney.

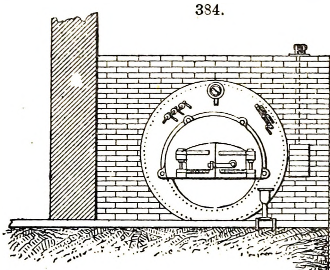
383.



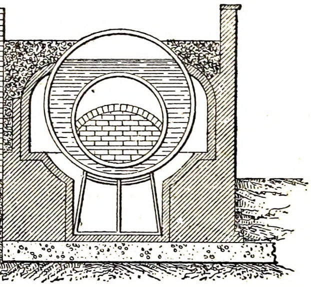
The Lancashire boiler differs from the Cornish, in having two furnace-tubes. In both types of boiler the shell is cylindrical, the ends are flat, and the furnace-tubes are carried through from front to back, below the ordinary water line, while the boilers are laid horizontally and fired internally. Internal firing is essential either to a Lancashire or to a Cornish boiler. If the fires are put underneath they are simply externally-fired single or double-flued boilers respectively.

Lavington E. Fletcher, in 1876, described a typical form of the Lancashire boiler which was the result of extended operation and practical research. To Fletcher we are mainly indebted for the following particulars, which apply to the Cornish boiler, and to all the variations of the Lancashire, as regards their setting, equipment, construction of shell and furnace-tubes, equally with the improved form advocated by him, which has been very generally adopted and found

384.

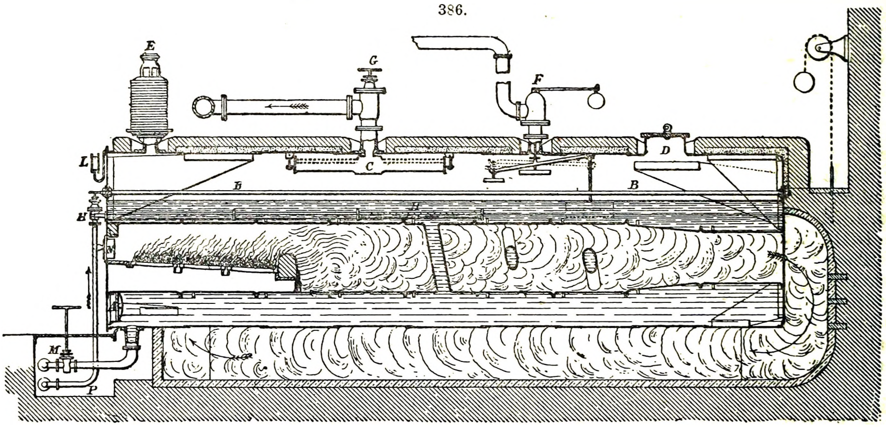


385.

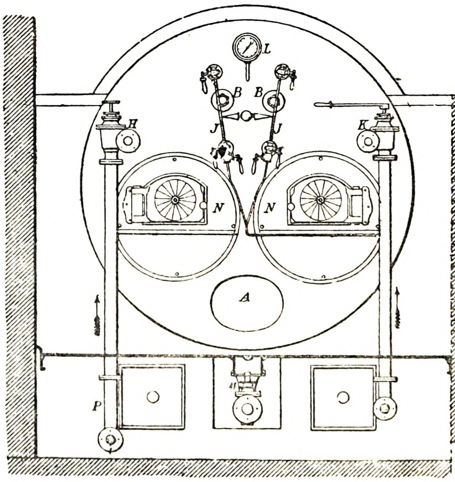


to give satisfactory results. This is shown in longitudinal section Fig. 386, Fig. 387 is an end elevation, and Fig. 388 a transverse section; it is safe for a working pressure of from 75 to 100 lb. a sq. in. Its structure is elastic, so that it may not be rent or disturbed by the movement of the parts, resulting from alternate expansion and contraction; and is so set and the fittings are so arranged that the whole may be accessible to inspection.

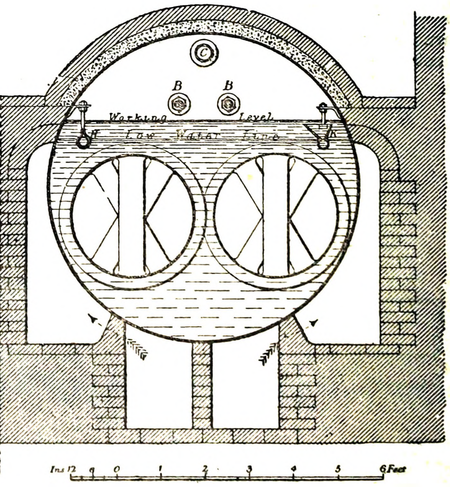
386.



387.



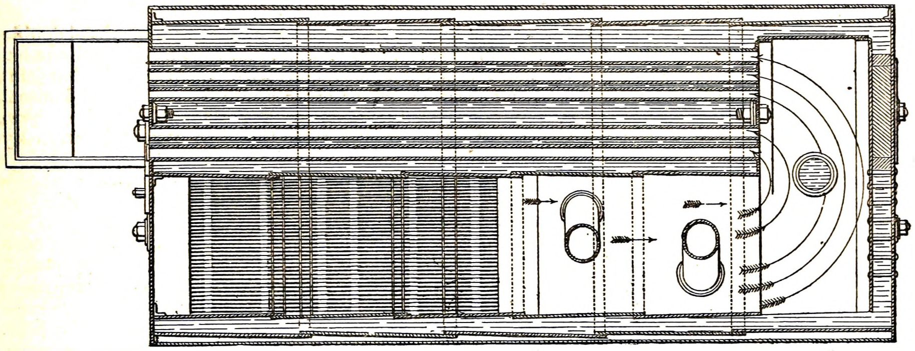
388.



The Lancashire boiler has many variations, besides the simple form, Fig. 386. Of these in the

Galloway boiler, the furnaces instead of running through from one end to the other unite in an oval flue strengthened with conical water pipes. That shown in plan, Fig. 389, is made very short, and one flue is removed and replaced with thirty-five tubes, the remaining flue contains the grate and is supported by two Galloway tubes. A large combustion chamber at the back is strengthened by a third tube of the same kind. Access can be had to the tubes at the back end through a manhole closed by a firebrick block. This boiler is adapted for use in confined situations, and is made so as to require no brickwork setting, the products of combustion being led off to a flue by a hood of wrought iron, seen in front of the tubes to the left of Fig. 389. In the Multitubular form, the furnace-tubes unite in a combustion chamber, from which a number of small flue tubes, about 3 in. diameter and 6 ft. long, run to the back of the boiler. Hill's Multiflued boiler has seven flues about 11 in. diameter and 8 to 10 ft. long, which take the place of the small flue tubes in the multitubular boiler. There are also others in which the furnace-tubes branch off to the sides or the bottom of the shell, instead of running right through to the back end.

389.



Short boilers are found to do more work in proportion than long ones; this has been confirmed by experiments on the rapidity of evaporation by Charles Wye Williams and others. Short boilers also strain less than long ones, and are therefore less liable to need repair. A length of 30 ft. should be the maximum; with regard to the minimum, some Lancashire boilers to suit particular positions have been made as short as 21 ft. and found to work well, though the fittings become rather crowded. The length recommended and now generally adopted is 27 ft.

The diameter of the boiler is governed by the size of the furnaces, which should not be less than 2 ft. 9 in. to admit of a suitable thickness of fire and afford convenience in stoking. Thick fires are more economical than thin ones. The space between the two furnace-tubes should not be less than 5 in., and that between the furnace-tubes and the side of the shell 4 in., in order to afford convenient space for cleaning and for the free circulation of the water, as well as to give sufficient width of end plate, for enabling it to yield to the expansion and contraction of the furnace-tubes. With this width of water space, it will be found that furnace-tubes having a diameter of 2 ft. 9 in. require a shell of 7 ft., which will afford a headway of about 2 ft. 9 in. from the crown of the furnaces to the crown of the shell. A furnace 3 ft. diameter gives room for a thicker fire than one 2 ft. 9 in., but it requires a shell 7 ft. 6 in. diameter. For high pressures, the smaller diameter of 7 ft. is generally preferred, and is adopted as a standard size for mill boilers throughout Lancashire, though one of 7 ft. 6 in. makes a good boiler and gives a greater Ind. H. P. to the lineal foot of frontage than one of 7 ft. The diameters both of the shell and of the furnace-tubes are measured internally, that of the shell being taken at the inner ring of plating.

The ends, more especially the front, are the seat of the grooving action which occurs in Lancashire boilers when disproportioned. These grooves occur inside the boiler and around the furnace mouth. They are the product of mechanical and chemical action combined. The plate is fretted by being worked backwards and forwards by the movement of the furnace-tubes, consequent on the action of the fire, and when in that condition is attacked by the water. To prevent this grooving, the ends should be rendered elastic so as to endure the buckling action without fatigue. To secure this elasticity there should be not only a sufficient width of end plate between the two furnace-tubes, as well as between them and the shell, as already explained, but also a space of 9 in. between the centre of the bottom rivet in the gussets and those at the furnace mouth. Five gusset stays are found to work in better than any other number. With five gussets, one falls on the centre line, which is not only the weakest part of the front end plate and thus where it requires the most support, but also where it can be held fast without resisting the movements of the furnace-tubes. The part of the end plate that should be left free is that immediately over the furnace crowns. With four gussets, the end plate is more unguarded at the centre, which is the weakest part, and more confined immediately over the furnace-tubes, which is the line of motion.

The thickness of the end plates is sometimes as much as $\frac{3}{4}$ in. for pressures of 60 lb. a sq. in. This thickness however is quite unnecessary, and only tends by its rigidity to cramp the furnace-tubes and strain the parts. Half an inch has been repeatedly and successively adopted in boilers for pressures of 75 lb. a sq. in., and $\frac{9}{16}$th in. when that pressure has been exceeded. These thicknesses have proved amply sufficient.

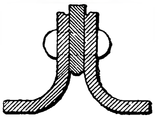
Longitudinal stays are frequently introduced to assist the end plates, though not absolutely necessary where the gussets are substantial. They are shown at B in Figs. 386 to 388, and are secured at each end with double nuts, and placed 14 in. above the level of the furnace crowns, as close together as convenience will allow. When placed directly over the furnace crowns, and only a few inches above them, they confine the furnace-tubes too strictly, and straining ensues.

To increase the elasticity of the front end plate, it should be attached to the shell by an external angle-iron, rather than by an internal one or by flanging. It is not necessary to attach the end plate at the back of the boiler with an external angle-iron, and when this has been done, the angle-iron has been found to be injured by the action of the flame.

Both of the end plates, instead of being made in two pieces riveted together at the joint, are welded, in the boiler, Fig. 386. This affords a flat surface, which in the case of the front end is more convenient for the attachment of the mountings. Also both of them are turned in the lathe at the outer edge, so as to be rendered perfectly circular, and are bored out at the openings for the furnace-tubes.

The longitudinal joints in the furnace tubes are welded when the plates are of iron, and double-riveted when of steel, each belt of plating being made in one length, and thus having but one longitudinal joint. All the transverse seams of rivets are strengthened with Adamson's flanged joint, or with an encircling hoop either of Bowling iron, T-iron, or other approved section. Adamson's flanged seam is shown in cross section in Fig. 390, the T-seam, Fig. 392, the Bowling hoop, Fig. 391, and the Bolton steel hoop, Fig. 393. One of the evils that has attended internally-fired boilers has been the frequent collapse of the furnace-tubes; but this danger is completely avoided by strengthening the tubes as just described, whereby, instead of being weaker than the shell as before, they are rendered stronger. This has been shown by experimental bursting tests, in which, while the shell has been burst repeatedly, the furnace-tubes have not suffered at all, nor shown any movement on being gauged. In some cases Petrie's water pockets, Figs. 395, 396 and in others Galloway's conical water pipes, Fig. 394, are introduced as a precaution against collapse; while in others again the water pipes are made parallel, as in Fig. 388, and either riveted or welded in place, so as to form one piece with the flue tube. In all cases, however, the transverse seams of rivets over the fire should be strengthened with flanged seams or encircling hoops; and it is desirable to continue this mode of construction throughout the entire length of the boiler, whether water pockets or water pipes are introduced or not.

390.



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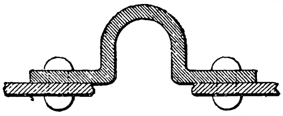

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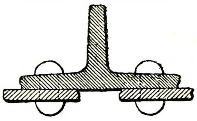

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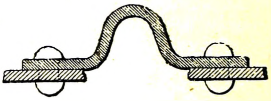

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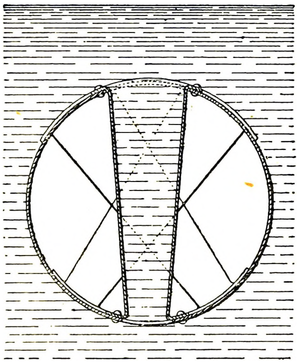

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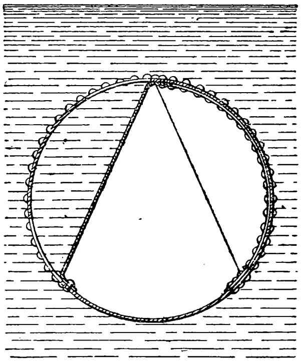
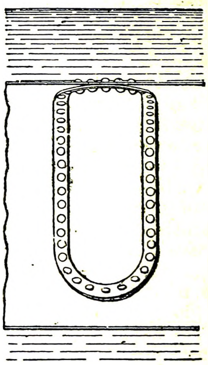


396.



The thickness of the plates in the furnace-tubes is sometimes as much as $\frac{1}{2}$ in. This leads to violent straining and frequent leakage at the furnace mouths, and other transverse seams of rivets. Many furnace-tubes 2 ft. 9 in. diameter, though only $\frac{5}{16}$ in. thick, have stood a hydraulic test of 120 lb. on the sq. in. without movement, and have worked satisfactorily for years at a steam pressure of 60 lbs. It is advisable, however, to have them a little thicker than this, in order to afford a margin for waste through corrosion, and also, when the flanged seam is adopted, in order to allow for the thinning that occurs in drawing the metal to make the flange. A thickness of $\frac{3}{8}$ in. is sufficient for a working pressure of 75 lb. on the sq. in., $\frac{13}{32}$ in. for a pressure of 80 lb. or 90 lb., and $\frac{7}{16}$ in. for 100 lb. on the sq. in.

Stays are sometimes introduced for supporting the furnace-tubes. Such stays, however, in the Lancashire boiler are unnecessary, and when rigid are decidedly objectionable. Furnace-tubes should be left free to move. As soon as a fire is lighted within them the top of the tube becomes hotter than the bottom and elongates. This makes the tube arch upwards. Furnace-tubes tyed to the shell often tear away from it in work.

The shell, which is $\frac{7}{16}$ in. thick for a pressure of 75 lb. on the sq. in., and $\frac{9}{16}$ in. thick for a pressure of 100 lb., is composed of plates about 3 ft. wide, which are laid in not more than three lengths round the circumference, in order that the longitudinal seams may clear the brickwork seatings. The longitudinal seams are so arranged as to break joint, and avoid the centre line along the top and bottom of the boiler.

There is no steam dome in the boiler, Fig. 386. Fletcher considers steam domes expensive, weaken the shell, and often give trouble from leakage at the base. Added to this they are inconvenient in carriage, as well as in revolving a boiler on its seat, which is sometimes desirable for repairs; they are also inconvenient in covering the boiler over, and in the great majority of cases, if not in every instance, they are for stationary boilers perfectly useless. To prevent priming, an internal perforated pipe C, Figs. 386, 388, is adopted in place of the dome.

The manhole D, Fig. 386, is guarded with a raised mouthpiece of wrought iron, welded into one piece, flanged at the bottom and attached to the boiler with a double row of rivets, the thickness of the upper flange being $\frac{7}{8}$ in., and of the body $\frac{3}{4}$ in. This has been found to stand a test of 300 lb. on the sq. in. without the slightest indication of straining. It is too frequently the practice not to strengthen manholes with any mouthpiece at all. Many explosions have arisen from this cause, rents starting in the first place from the unguarded manhole, and then extending all over the boiler. The loss of strength is owing not only to the loss of metal cut away by the opening, but also to the action of the cover, which in unguarded manholes is generally internal. This internal cover bears on a narrow edge of plating all round, and is driven outward by the pressure of the steam, and also pulled in the same direction by the bolts in tightening the joint. In fact the cover acts as a sort of mandrel, which being forcibly driven through the manhole splits the boiler open. A heavy hydraulic test shows this action of the cover, by curling the boiler plate up around the manhole. Added to this, the joint is apt to leak, and thus to induce corrosion and thin the plate, which not only reduces its strength, but leads to extra force being applied to tighten the joint. It has been the general practice to make raised mouthpieces of cast iron. This, however, is not wise for the high pressures now in use. A raised manhole having a clear opening of 16 in. diameter, which is the usual size, involves a hole in the shell plate at its base of about 20 in. diameter. The plate in which this hole is cut, unless it is duly strengthened, becomes the weakest part of the boiler when the longitudinal seams are double-riveted, the furnace-tubes suitably strengthened with encircling rings, and the ends well stayed; so that the stability of the entire structure depends on the manhole, if that fails, the whole structure fails. Under these circumstances it is evidently unwise to risk the safety of the boiler on a piece of cast iron.

The mudhole A, Figs. 386, 387, at the front of the boiler, beneath the furnace-tubes, is also fitted with a substantial mouthpiece. This in some cases is external, like the manhole mouthpiece, and in others internal, as in Fig. 386. The internal ones have the advantage of being less in the way. In either case the surfaces at the joint, between the body of the mouthpiece and the cover, are faced true, so that the parts may be brought together metal to metal.

The safety-valves E and F, and the steam stop-valve G are fixed to the shell, each with its own independent opening, and not grouped upon the manhole mouthpiece as is sometimes the case.

In old-fashioned practice the fittings were bolted directly to the cylindrical portion of the shell. This led to the wasting of the shell through leakage at the joints; so that it has long since been the practice to rivet short stand-pipes to the cylindrical portion of the shell, and bolt the fittings thereto, the joint surface between the flanges being planed up true. These stand-pipes, frequently termed fitting blocks, are not only more convenient for the attachment of the fittings, but also, being riveted to the plate and made of substantial section, strengthen the plate round the hole cut in the shell. They are as a rule made of cast iron, but it becomes a question whether, with the high pressures now in use, they should not be made of wrought iron.

The seams of rivets running longitudinally in the cylindrical shell are all double-riveted, with $\frac{3}{4}$ in. rivets, pitched about $2\frac{1}{2}$ in. longitudinally and 2 in. diagonally. The remaining seams throughout the boiler are single-riveted only, the rivets being 2 in. pitch.

The riveting is done by machine in preference to hand in the cylindrical shell, in the furnace-tubes, and as far as practicable in the flat ends. The rivet holes in the angle irons, T-irons, and flanged seams are drilled, those in the plates being punched by most makers; though by some the holes are drilled throughout, and the practice of drilling is strongly advocated by them. The edges of the plates at the longitudinal seams of rivets are planed and caulked lightly, inside as well as out; though in many cases caulking is superseded by fullering.

As a rule, boilers of this description are of iron in the shell, while steel plates are frequently introduced in the furnace-tubes for a length of 9 ft. over the fire, and sometimes from one end of the boiler to the other. For the furnace-tubes steel plates have been found to answer well, but "best best" iron plates from first-class makers are employed for shells, more importance being attached to their ductility than to their tensile strength. Brands, however, are uncertain, and it is desirable that a complete system of testing should be adopted before a boiler is made, one plate out of the set proposed to be used being tested as a check, the investigation having special reference to ductility. Low Moor rivets are frequently used.

The fittings are so arranged, that those requiring frequent access are immediately within reach of the attendant, when standing in front of the boiler. The feed is introduced on one side of the front end plate, about 4 in. above the level of the furnace crowns, an internal dispersing pipe H, Figs. 386 to 388, being carried along inside the boiler for a length of about 12 ft., and perforated for the last 4 ft. of its length. On the opposite side of the front end plate is fixed the scum tap, to which is connected a series of sediment-catching troughs K, Fig. 388, fixed inside the boiler. In the centre of the end plate are two glass water-gauges J J, Fig. 387, so that one may act as a check upon the other, a pointer being fixed to show the correct height at which the water should be kept. Immediately above the water-gauges is a dial pressure-gauge, and above that a dead-weight safety valve E. Thus whenever the attendant opens the furnace doors to charge the fires, he has the height of the water and the pressure of the steam directly before him. Under his feet is the blow-out tap, and behind him the coal supply, so that everything is ready to hand. He has not to climb a ladder in order to reach the water-gauges, or ascertain the steam pressure, nor to mount on the top of the boiler in order to regulate the feed supply. A handle for regulating the dampers is frequently brought to the boiler front. On the top of the boiler are two safety-valves, one a dead-weight valve E, the other a low-water valve F, Fig. 386.

But convenience in manipulation is not the only reason for this arrangement of fittings. If the feed is cold and introduced near the bottom of the boiler, it is apt to induce local contraction, and strain the transverse seams of rivets at the bottom of the shell; but when introduced near the surface of the water, and passed through an internal perforated pipe, it becomes dispersed before falling to the bottom. Further, although non-return valves may be introduced, they will sometimes fail and permit the water to escape, allowing the furnace crowns to become bare and overheated. When the feed inlet is placed above the level of the furnace crowns, it will be seen that they cannot be drained bare by leakage at the non-return valve; but when placed at the bottom of the boiler, the boiler may then be emptied by such an occurrence.

The furnace mouthpieces N N, Fig. 387, are of wrought iron, finished off with a brass beading, and kept within the circle of the rivets, so as to leave them exposed to view. The firedoors are fitted with a sliding ventilating grid on the outside, and a perforated box baffleplate on the inside, the aggregate area of the air passages being about 50 sq. in. for each door, or about 3 sq. in. to each sq. ft. of firegrate. The firegrate is 6 ft. long, with the bars in three equal lengths, about $\frac{3}{4}$ in. thick, and spaced $\frac{3}{8}$ in. apart. The bearers consist of two wrought-iron bars, carried on wrought-iron brackets, riveted to the sides of the furnace-tubes. The standard length of grate is 6 ft., but a shorter one is productive of economy, though the concentration of the fire is more trying to the boiler, and has been found, where the feed water has not been good, to injure the furnace plates, and render lengthening the grate necessary.

All connection to boilers should be elastic, so as to allow of their movement. If the main steam-pipe is carried across the boilers and bolted direct to the steam junction-valve, the joints are strained by the rising and falling of the boilers, as they are set to work or laid off. To prevent this, a spring length should be introduced between the steam stop-valve G and the main steam-pipe, as in Fig. 386. Where the main steam-pipe has a considerable length to travel to the engine, it should not be taken in a direct line, but should either be carried round the boiler house or be led in a horse-shoe shaped course, to give elasticity; this is better than introducing an expansion joint, which is not always reliable. The feed connection should be elastic; for this purpose a copper elbow connecting-pipe P, Figs. 386, 387, is introduced between the main feed-pipe and the stand-pipe; in some cases a wrought-iron horse-shoe shaped pipe has been adopted instead with very satisfactory results.

Connections between the steam stop-valve and main steam-pipe are frequently made to incline upwards, but the steam-pipe should drain towards the engine, and not towards the boilers, its course being intercepted by a separator, fixed as near the engine as convenient. The principle on which these separators act is that of making the steam take a sharp turn, so as to shoot off the water mixed with it into a catch-chamber prepared for the purpose.

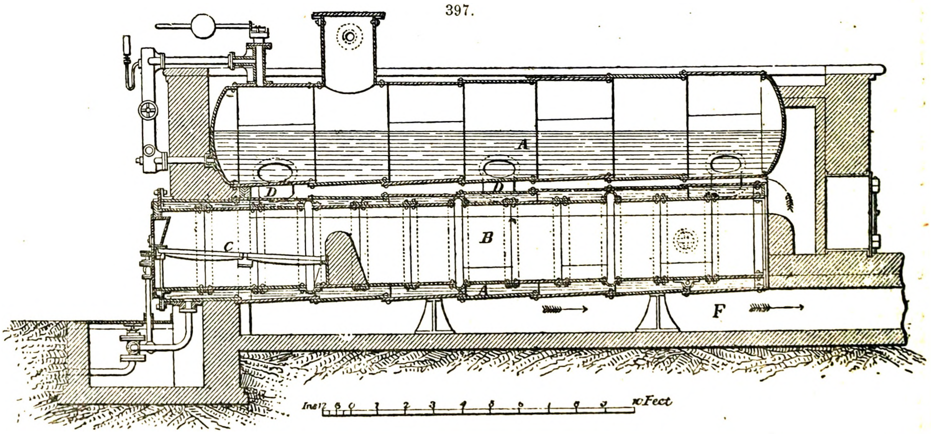
The weight of such a boiler as that in Figs. 386 to 388, when 7 ft. diameter, 27 ft. long, and made of plates $\frac{7}{16}$ in. thick, is about 12 tons without fittings; with fittings $15\frac{1}{2}$ tons.

It has a heating surface in the external shell of 370 sq. ft.; in the furnace-tubes, without water pipes, 450 sq. ft.; in the water pipes 30 sq. ft.: making a total of 850 sq. ft. The firegrate has an area of 33 sq. ft.; this gives for every square foot of firegrate 26 sq. ft. of heating surface.

In feed-water heaters the surface varies; sixty pipes, each affording a heating surface of about 10 sq. ft., are frequently introduced for each boiler, making a total heating surface of 600 sq. ft., or about three-fourths of that in the boiler.

From 15 to 20 tons of coal in a week of sixty working hours, or from 17 lb. to 23 lb. to each sq. ft. of firegrate an hour, may be burnt in such a boiler without distressing it or making smoke, all that is needed is to maintain a good thickness of fire, throw on the coal little and often, admit a little air above the bars for a short time after firing, and avoid the use of the rake. The coal may either be spread over the whole surface of the fire, or thrown at alternate firings first to one side of the furnace and then to the other, on the side firing system.

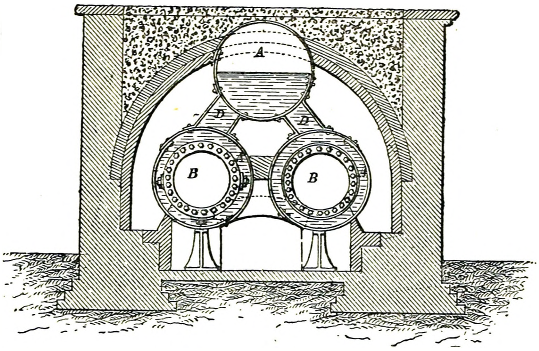
397.



The boiler, Figs. 397, 398, is of the form designed by Fairbairn, with a view of securing great strength and extended heating surface. That seen in the figures is intended for pressures up to

150 lb. on the square in. It consists of three exterior wrought-iron tubes A A, 22 ft. long and 3 ft. 9 in. diameter, two of them having internal tubes, B B, of the same length by 2 ft. 9 in. diameter, containing the furnaces C. The flames pass along the entire lengths of the furnaces to the ends, where they combine, and return over the top of the lower tubes, and along the bottom of the upper tube, which is half full of water, and thence passing downwards below the lower tubes to the flue.

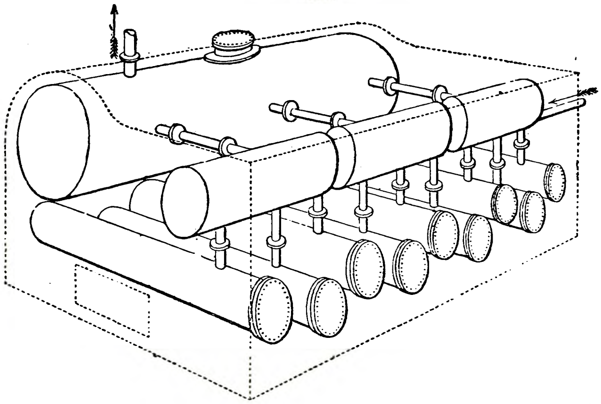
398.



Circulation is maintained by means of six connecting tubes D D, arranged along the length of the boiler. The furnace flues are attached to the two bottom tubes by faced joints and screw bolts at each end; internal rollers are also attached to the bottom and sides, and, by unscrewing the bolts at the ends, the flues may be withdrawn, thus rendering the interiors of the tubes accessible for cleaning or repairs. Such boilers generate steam rapidly, but are somewhat expensive to manufacture.

Boilers designed with the two-fold object of small water-space and small areas exposed to pressure, occupied much attention when high pressure steam was first used, and have again come into favour from the proved economy of higher pressures of steam than are safe with ordinary boilers; they therefore deserve careful consideration. The objects aimed at in boilers of this class are, to remove danger by avoiding large accumulations of highly heated water, and to make the parts so small as to avoid severe strains on the material of construction.

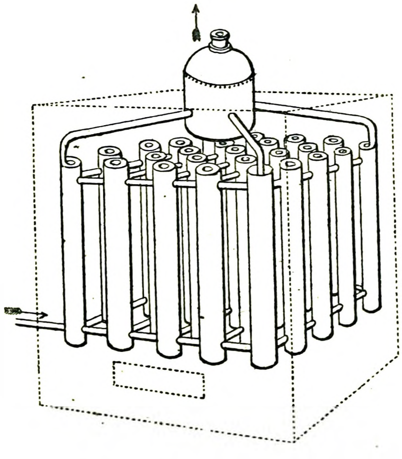
399.



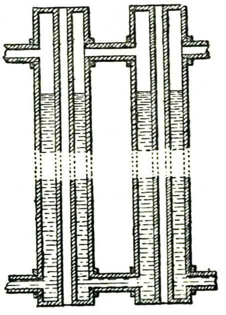
Some of the earliest high-pressure boilers were made of cast-iron pipes of small diameter, as in the early Woolf boiler, Fig. 399, which consisted of a layer of horizontal cast-iron pipes, 12 in. diameter, exposed to the direct heat of the fire externally, connected above to a larger pipe and this again to a steam receiver. In this boiler the principle of employing small water spaces, and areas exposed to pressure, was well carried out, but the mode of constructing the joints rendered them neither durable nor safe.

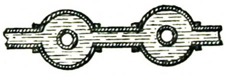
When locomotives were first employed on the common roads, some ingenious forms of tube boilers were designed, such as Hancock's, Fig. 400, which consisted of a set of vertical wrought-iron tubes $4\frac{1}{2}$ in. diameter, arranged in parallel rows, each tube having a small flue-tube 2 in. diameter passing through it, for increasing the heating surface, as in Figs. 401, 402. The

400.



401.

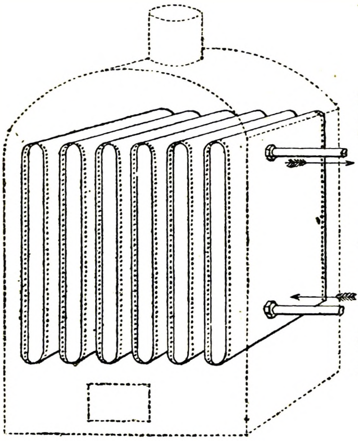




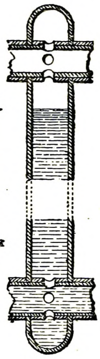
402.

tubes were connected together by small feed and steam pipes, and communicated with a steam receiver on the top, and the whole was enclosed in an external iron casing. Another arrangement for a similar purpose was Ogle's boiler, illustrated at p. 432 of this Dictionary. Both these plans of boilers were used with success, and attempts were also made to use a set of thin flat chambers, as in Hancock's boiler, Fig. 403, connected together at top and bottom by a single steam pipe and feed pipe, Fig. 404. The flat chambers, however, were found to depend for strength too much upon stays, and various plans of corrugated and bulged plates were tried with indifferent success.

403.



404.



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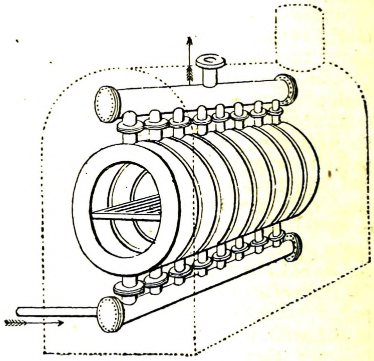
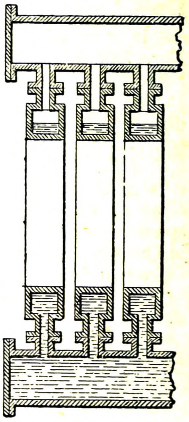


James' boiler, Fig. 405, already described at page 430 of this Dictionary, was composed of a series of annular cast-iron tubes, about 6 in. sq. in section, and 3 ft. diameter inside, which were placed side by side, and connected together by a water pipe at the bottom and a steam pipe at the top, as in Fig. 406; the cast-iron tubes thus formed a cylindrical space, within which the fire was placed, the whole being enclosed within a metal case.

406.

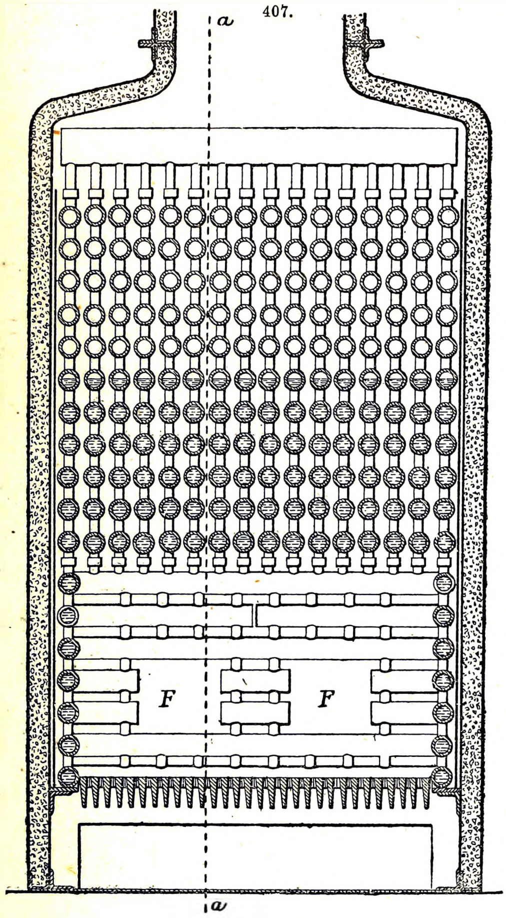


When it was found that vessels of large diameter could be made of riveted plates, and capable of standing high pressures, the early small water-space boilers fell into disfavour, and the few then designed were little used. It has only been recently that the principle of small water-space boilers has been revived, in consequence of the rapidly growing demand for higher pressures of steam than are admissible with the ordinary large boilers; and the following examples will serve to illustrate briefly the very ingenious principles of construction that have been brought out for this purpose. One of the earliest was Perkins high pressure boiler, described at page 465 of this Dictionary; boilers on this plan are still at work.

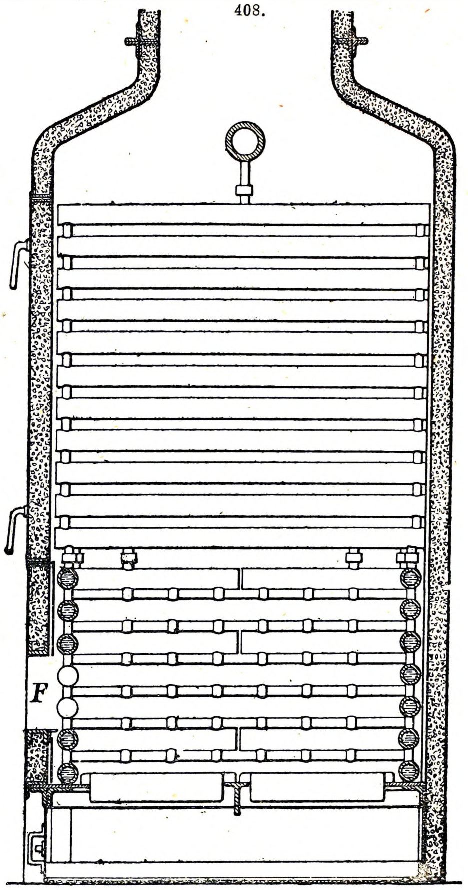
The construction of the improved Perkins boiler, as described by the inventor in 1877, is shown in Figs. 407, 408. The horizontal tubes are $2\frac{1}{4}$ in. internal and 3 in. external diameter, excepting the steam collecting tube, which is 4 in. internal and $5\frac{1}{2}$ in. external diameter. The horizontal tubes are welded up at each end $\frac{1}{2}$ in. thick, and connected by small vertical tubes, Figs. 409, 410, of $\frac{7}{8}$ in. internal and $1\frac{5}{16}$ in. external diameter. The firebox is formed of tubes bent into a rectangular shape, placed $1\frac{3}{4}$ in. apart, and connected by numerous small vertical tubes $\frac{7}{8}$ in. diameter. The body of the boiler is made of a number of vertical sections, composed of eleven tubes, connected at each end by a vertical tube; these sections communicate at both ends by vertical tubes with the top ring of the firebox, and to the steam collecting tube.

The Perkins vertical connecting pipes are screwed into the horizontal tubes with right-and-left-hand threads, in the case of all the tubes forming the separate vertical sections above the firebox, being screwed simultaneously into the upper and lower tube, at A A, Figs. 409, 410. The ring tubes forming the firebox are connected by backing-out joints, like those used in making gas connections, the connecting pipe being screwed with a right-hand thread at both ends, as at C C; in putting the rings together, the short connecting pipe is first screwed up into the upper ring to double the required distance, and then backed down into the lower ring; so that, whichever way the connecting pipe is turned, it screws itself in at one end and out at the other. This arrangement affords the means of taking out and replacing any one of the ring tubes forming the firebox, without altering the vertical distance apart, between the adjacent tubes above and below. For connecting the main sections of the boiler with the steam collecting tube at top, and with the firebox ring tube below, a differential joint B is used. A separate short pipe is screwed right-hand into each of the tubes to be connected, the threads being 15 to the in., as in all the rest of the joints throughout the boiler; and these two connecting pipes are united by a coupling socket, screwed right-hand at both ends, but with 11 threads to the in. at the top end and 15 at the bottom; this socket is first screwed down to double the required distance upon the lower connecting pipe, and then backed upwards upon the upper, the differential thread having the effect of drawing together the two ends of the connecting pipes, and thereby compressing a copper washer inserted between them, to form a perfectly steam-tight joint. All the screwed joints into the tubes of the boiler are made tight by caulking, after being screwed up. The differential joints admit of taking out and replacing any one of the sections of the boiler over the fire, without interfering with any of the others.

407.



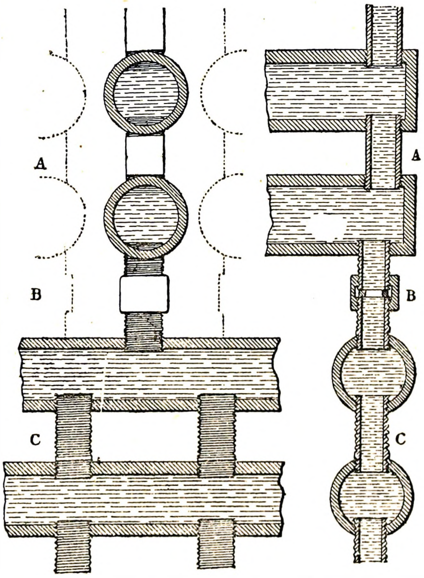
408.



The whole of the boiler is surrounded by a double casing of thin sheet iron, filled up with vegetable black to avoid loss of heat. Every tube is separately proved by hydraulic pressure to 4000 lb. on the sq. in., and the boiler in its complete state to 2000 lb., this pressure remaining in for some hours without showing any signs of leakage. Experience of a very extensive character has proved that this construction of boiler can be worked safely, with great regularity, and without priming, and that the steam produced is remarkable for its freedom from moisture. The area through the vertical connecting tubes is found ample for allowing of the free escape of the steam, and for the prevention of injury from overheating of the tubes in contact with the flame.

Combinations of small wrought-iron tubes have been employed in various ways for boilers, and an example of one arrangement is the Belleville boiler, Figs. 411, 412. This consists of a series of parallel horizontal tubes about 4 in. diameter inside, each of which is carried up from the bottom to the top of the boiler, by a succession of bends overlying one another; and each thus forms a separate course, from the feed pipe running along the bottom to the steam pipe along the top.

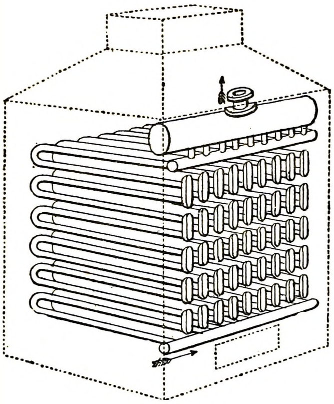
409. 410.



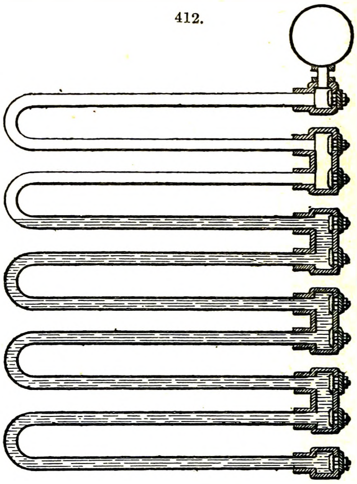
Another arrangement is the Jordan boiler, Figs. 413, 414, consisting of rows of vertical tubes $8\frac{1}{2}$ in. internal diameter, connected together in each row at top and bottom.

A boiler on an entirely different principle of construction is the Harrison boiler, Figs. 415, 416, which is composed entirely of a number of small hollow cast-iron balls of 8 in. external diameter, cast in sets of four balls, and arranged in parallel inclined lines; the balls in each line are in communication throughout, and are strung together upon a long bolt that is screwed up at each end; the several lines of balls communicate together in vertical rows, Fig. 416. This plan of boiler is in considerable use in America; but it has not proved successful in England, owing to the trouble caused by the liability of the cast-iron balls to split in working, and the delay of removing and replacing them, and also in consequence of the difficulty of keeping all the numerous joints steam-tight. The castings are all made with faced joints, finished to an exact gauge and fitted together metal to metal; and the very accurate adjustments that have consequently to be maintained throughout, for keeping all the numerous joints steam-tight, is liable to be disturbed by irregular expansion occurring in working the boiler. The shape of the balls is also found objectionable, in consequence of their forming a succession of pockets throughout the water space, and thus serving for the retention of deposit.

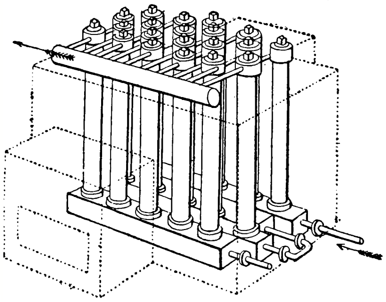
411.



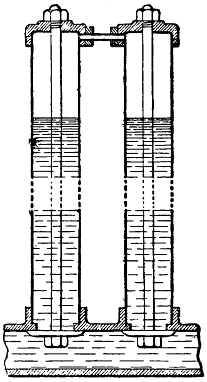
412.



413.



414.

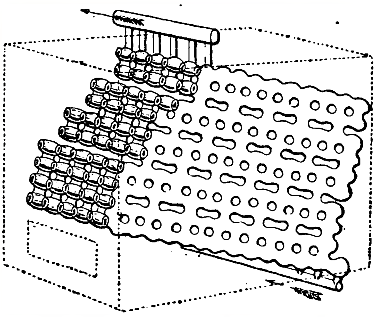


Another novel boiler is that of Benson, shown at page 474 of this Dictionary, and to which we need not further allude.

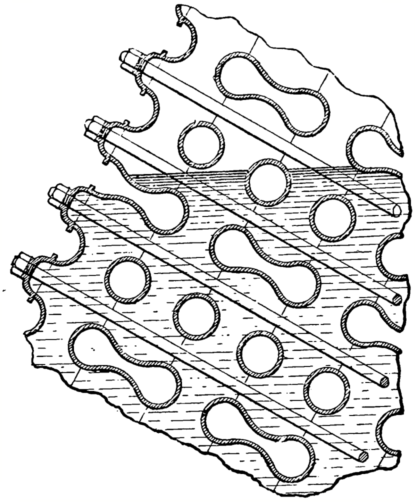
The demand for steam fire-engines led to the introduction of boilers for generating steam very rapidly, and having small vertical tubes hanging down into the fire with their lower ends closed. These boilers have a reservoir of water of some extent externally, but by filling up the space with hollow copper vessels, suspended inside the tubes, the quantity of water contained in the boiler is reduced to a small amount, in order to allow of getting up steam in a very short time. A difficulty was found, however, with these pendent water tubes, from their soon becoming choked up with deposit and getting burnt; and the steam was sometimes generated so rapidly in the tubes as to blow the water out, causing the tubes to be overheated and consequently to get out of shape and become leaky. This difficulty was then overcome by obtaining a continuous circulation of water in the tubes, by the introduction of small internal circulating tubes, through which a down current of cooler water is secured from the reservoir above, undisturbed by the rising steam in the upward current of heated water in the outer annular space.

The circulation action was rendered more certain by the funnel-shaped top of the internal Field tube shown at p. 472 of this Dictionary. This plan has also been used to a considerable extent as an addition to ordinary large water-space boilers, for increasing their heating surface.

415.

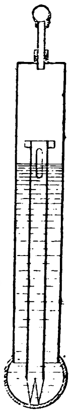


416.

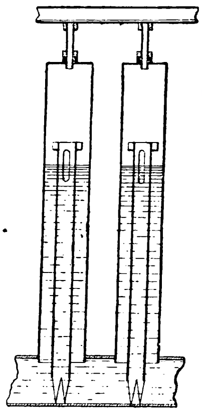


In the Howard boiler, p. 469, a series of horizontal wrought-iron tubes of ᗜ section are arranged longitudinally in a layer over the fire, and on each of them stands a row of vertical wrought-iron tubes, each containing an internal circulating tube, Figs. 417, 418. The vertical tubes are about 8 in. diameter, and are screwed into the flat side of the bottom horizontal tubes; they are closed at the top with a solid welded end, into which a short piece of gas pipe is screwed, connecting each row of tubes to a horizontal steam pipe above.

417.



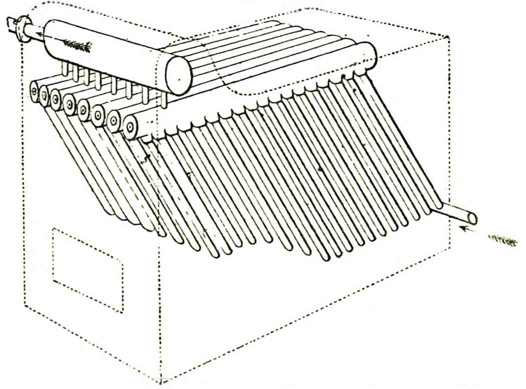
418.



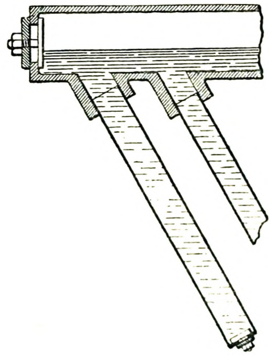
The Allen boiler, Figs. 419, 420, which is in use in America, has a series of rows of pendent inclined tubes about 5 in. diameter, closed at the bottom, and all exposed to the fire. The tubes in each row are connected at the top by larger horizontal tubes, which communicate with a steam receiver above; the inclined tubes are filled with water, which also half fills the horizontal tubes. There are not any circulating tubes within the pendent tubes, but these are placed inclined with the object of obtaining a circulation, by the feed water descending on one side and the steam ascending on the other side.

Figs. 421 to 423 are of Firminich's boiler; Fig. 423 and part of Fig. 422 are transverse sections; Fig. 421 a longitudinal view, with part of the brick casing removed, and the right hand side of Fig. 422 a half front elevation. The boiler consists of five horizontal tubes, the upper one of which is used as a steam chamber, and is connected by two short pipes on each side to the lower tubes in the top of the boiler. These latter are formed with a flat portion underneath, and correspond in section with the two under tubes. The lower and upper sections are connected with double and parallel rows of tubes, converging from the lower to the upper horizontal tubes. The lower tubes are connected with a horizontal circulating pipe, and at the rear of the boiler are blow-off and feed pipes, Fig. 421. There are altogether one hundred of the long inclined connecting tubes, twenty-five in each row, but these are not spaced at equal distances apart throughout, wider spaces being left at two places for the introduction of

419.



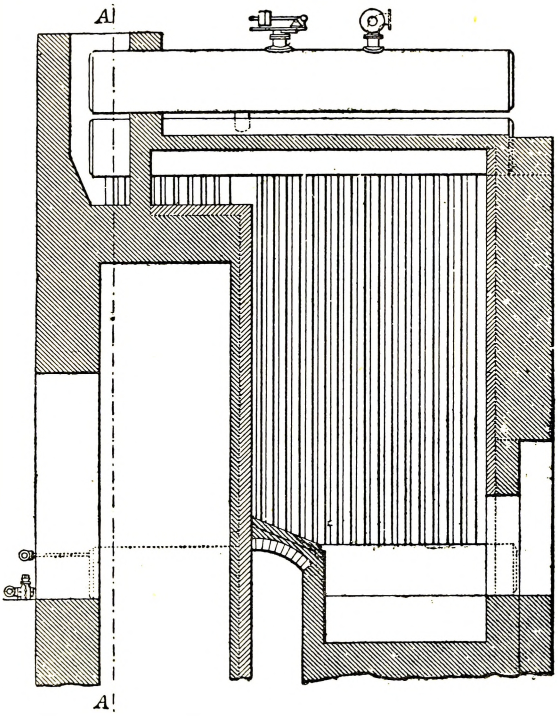
420.



deflecting walls, to prevent the direct escape of the heat from the furnace. Our figures are of an example which was exhibited at the Philadelphia Exhibition, which was rated at 100 horse-power.

A class of boilers has been made in which the water space is reduced by the introduction of a large steam space in the interior of the water, or by having a series of concentric chambers of water and steam alternately; but as in all such cases there is still a single external cylindrical shell of large size, these boilers are similar to ordinary large boilers, in their exposure to risk of explosion from high pressure acting upon a large extent of surface.

421.



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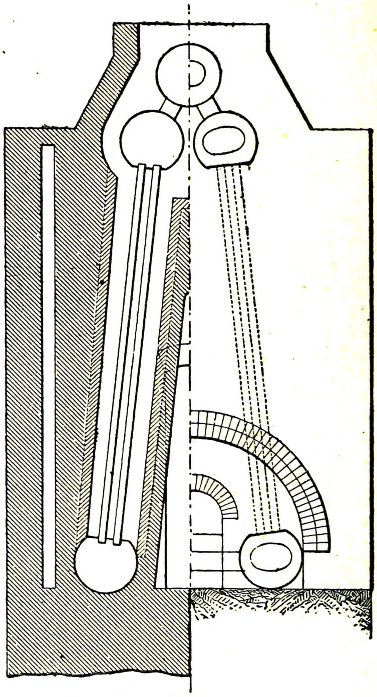


The following Table, due to Charles Cochrane, of Middlesborough, to whose researches we are principally indebted for the information here given on tube boilers, affords a comparison of the water contents in several constructions of boilers, in relation to their respective heating surfaces; as the basis for the comparison, an ordinary Cornish boiler having 500 sq. ft. of heating surface is taken, the dimensions being about 30 ft. length and 6½ ft. diameter; and the same extent of heating surface, 500 sq. ft., is assumed in each of the other boilers.

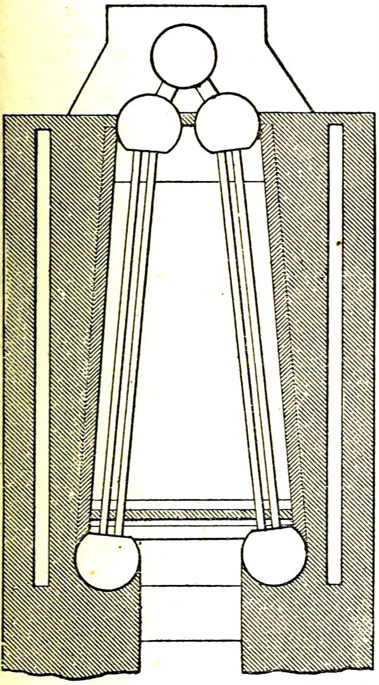
Proportion of Water Contents to Heating Surface in Boilers.

Class of Boiler.	Heating Surface.	Water Contents.	Space occupied.	Approximate Dimensions.	
				No. of Boilers.	Size.
	sq. ft.	cub. ft.	cub. ft.		ft. ft. ft.
Chimney	500	1120	3,000	4	25 × 5, 2½ tube.
Balloon	500	1005	10,000	1	18 × 18.
Furnace	500	909	7,680	1	25 × 9½.
Cylinder	500	775	4,000	1	80 × 4½.
Lancashire	500	404	2,700	1	28 × 6½, 2½ tubes.
Cornish	500	375	2,900	1	30 × 6½, 4 tube.
Locomotive	500	70	360	1	10 × 4.
Tube Boilers, average ..	500	40	760	1	60 tubes or more.
Steam Fire Engines	500	27	250	5	5 × 2.

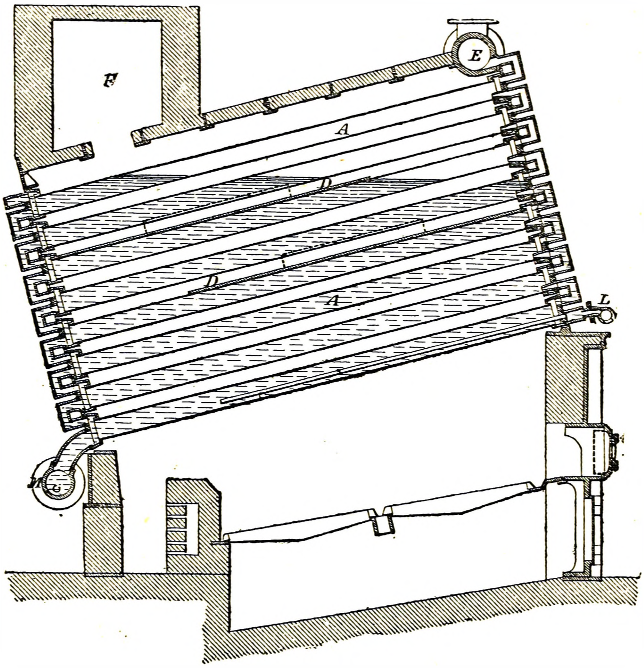
From this Table it will be seen that whilst the Cornish and Lancashire boilers have about 400 cub. ft. of water for the 500 sq. ft. of heating surface, the Furnace, Balloon, and Chimney boilers have more than double the proportion of water contents, but in the tube boilers the proportion amounts to only one-tenth, or 40 cub. ft. of water.

Root's boiler consists entirely of a series of similar wrought-iron tubes A A, Figs. 424, 425, arranged in parallel layers with clear spaces between all the tubes, and the tubes in each layer are over the spaces in the layer below. The tubes are placed at an inclination of 1 in 3, rising from the back towards the front, Fig. 424, and are connected together at both ends by caps C C, Fig. 426, which couple each tube both to the one below and the one above, so as to form a continuous communication, in a zig-zag direction, between all the tubes in each successive vertical row. The furnace chamber is directly below the boiler, and extends to the same width and length; and the flame and heated gases pass up between the tubes, and escape at a flue F at the top, which passes down outside to the chimney flue. The heated gases are made to traverse the length of the boiler three times in passing from the furnace to the exit flue, by three light cast-iron deflecting plates D, resting upon the tubes and closing the passage between them, for about three quarters of their length from either end alternately.

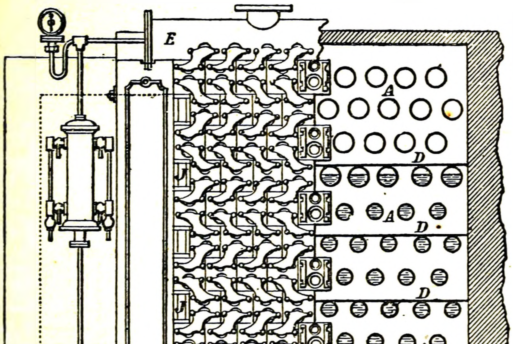
423.



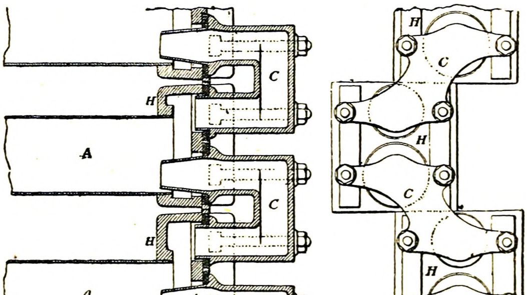
424.



425.



426.



The tubes are wrought-iron lap-welded tubes, 4 in. external diameter in the lower rows, 5 in. in the upper rows, and 9 ft. long. They are screwed at each end into a square cast-iron head H, planed on the four sides, and finished to a uniform gauge of 7½ in. width and 8 in. height. The heads are fitted close together, metal to metal, in the boiler, so as to form the front and back walls of the boiler setting, Figs. 424, 425. Each of the tube heads has two circular openings on the outer face, one above the other, Fig. 426; and oblique hollow cast-iron caps C are fitted upon these, to form the connections to the adjoining tubes above and below. The joints for these caps are made each by a single indiarubber washer $\frac{3}{8}$ in. thick, fitted into an annular recess, and secured by a couple of ┳-headed bolts, fitting into snugs cast upon the tube heads, with nuts outside.

The two sides of the boiler are enclosed by brickwork, which is carried down to form the walls of the furnace chamber below; and the top is covered in by fire tiles, resting on transverse iron girders, with a coating of sand or ashes above to keep in the heat. A row of cleaning holes J J, closed by stoppers, is formed at each end of the boiler, extending up each side, and serving for examining the boiler, and for cleaning the exterior of the tubes from any deposit of soot and dust. This cleaning is done by a small steam jet from a flexible pipe, which is inserted in the several cleaning holes; and by this means the boiler tubes are readily kept clean, and the passages between them prevented from getting choked. Each end of the boiler is enclosed by a pair of iron doors for the purpose of protection.

The water level of the boiler is at about two-thirds of the total height. The upper tubes are used as a steam chamber, and communicate with an external steam receiver E, 12 in. diameter, which extends across the top of the boiler. The connections from the several tubes are made by caps, fitted upon the top tube-heads in exactly the same manner as the rest of the connecting caps C. There are 90 tubes in all, having a total heating surface of 920 sq. ft., and 58 cubic ft. contents of water including the end caps.

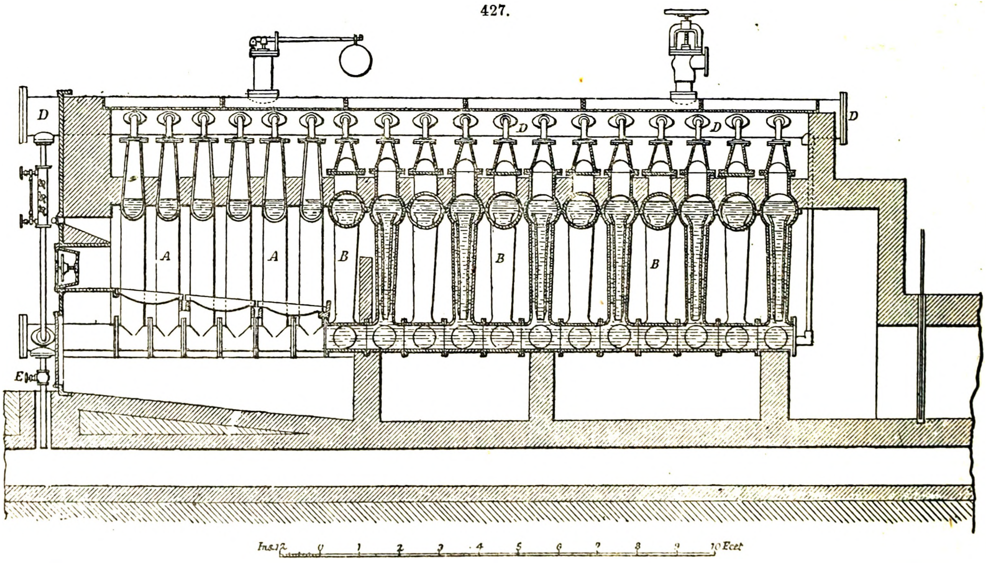
The blow-off and feed, Fig. 424, is arranged so that the blow-off pipes all discharge into one transverse mud-drum M, and a single blow-off cock at one end of the drum is connected to an internal pipe within the drum, which has an opening opposite each of the branch blow-off pipes. The aperture of the blow-off cock is made larger than the collective area of the holes in the internal pipe, to ensure blowing off simultaneously from the whole of the lower row of tubes to the full extent. The feed L is introduced in the bottom layer of tubes at the opposite end to the blow-off, and the feed pipe is prolonged within each tube, by an internal pipe extending about two-thirds of the length, with the object of partially heating the feed water before its discharge from the pipe into the boiler.

In this construction of boiler, the only portions that are exposed to the action of the fire are the exterior surfaces of the tubes, and the inner faces of the cast-iron heads. The tubes are plain cylinders with lap-welded longitudinal seams; and their small diameter allows of the metal being only $\frac{1}{8}$ in. thick for a steam pressure of 100 lb. or upwards, with an ample margin of strength, as this thickness gives the same tensile strength as 2 in. thickness in a boiler $6\frac{1}{2}$ ft. diameter. The tubes are all proved to a pressure of 500 lb. on the square inch before being fixed in the boilers.

Cochrane states that in some experiments made with Root's boiler, the consumption of coal amounted to 633 lb. during a period of 3 hrs. 33 mins., and the quantity of water evaporated during the same time had been 630 gallons; the results were therefore a consumption of 178 lb. of coal an hour, and an evaporative duty of nearly 10 lb. of water to the lb. of coal. The temperature in the chimney flue during this time ranged from 300° to 366° F., the firing being with coal.

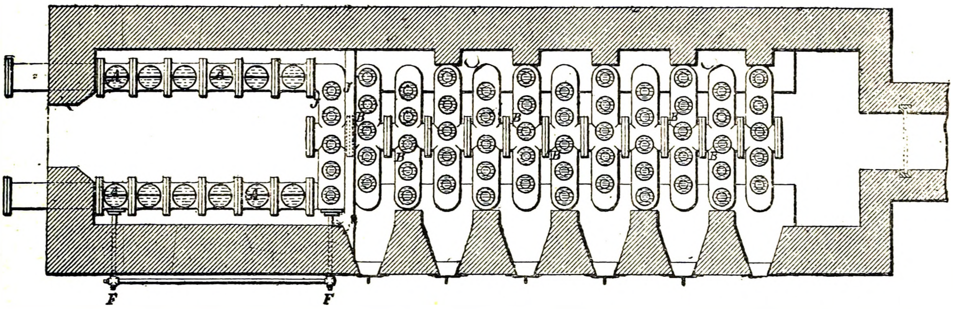
Miller's cast-iron boiler, Figs. 427 to 430, is constructed of a series of separate cast-iron sections, joined together at the base of each by flanges and bolts. The sections are of two patterns, each of comparatively small size, so as to contain only a small quantity of water; those at the front end are ∩-shaped tubes A A, forming a succession of arches over the firegrate. The rear sections B B consist each of five vertical tubes cast in one piece, as shown in Fig. 430, united by a transverse horizontal tube at bottom and top, and finished at the top with a flange joint upon which is fixed a

427.



cover. The several sections are bolted together at the bottom by flange joints, the front arched sections having two connections, one in each leg, and the rear sections a single one in the centre; these connections form continuous longitudinal tubes at the bottom of the boiler, which are closed by a flanged cap at each end. The tubes of the firebox sections are 7 in. diameter inside, and 2 ft. 4 in. width in the arched opening; the vertical tubes of the rear sections are taper in form, 4 in. diameter inside at bottom and 6 in. at top, and they are 2 ft. 6 in. length in the vertical portion, with an average of 2 in. clear space between the tubes. The connecting flanges of the rear sections are placed out of centre with regard to the tubes, so that reversing the sections brings the spaces of one opposite the tubes of the next, for the purpose of intercepting the flame and heated gases more effectually. The castings are $\frac{1}{2}$ in. thick, the rear sections weigh about 10 cwts., and the front arched sections are about 5 cwts. each.

428.



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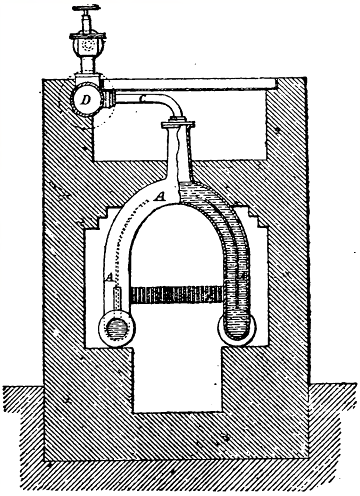
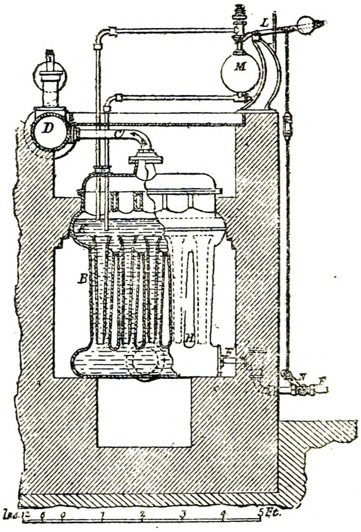


430.



In the front sections a longitudinal midfeather is cast in each leg, Fig. 429, extending nearly to the top and bottom, by which the ascending current of heated water on the inner side exposed to the fire, is separated from the descending current of cooler water on the outer side. In the rear sections an internal circulating tube is suspended in each of the vertical tubes, Fig. 430, causing the heated water to ascend through the outer annular space, and the cooler water to descend within the circulating tube, which is of cast iron and is held central by snugs cast upon it. The steam is taken off from the top by a 2 in. wrought-iron branch pipe C, bent at right angles, and connected to a horizontal cast-iron steam main D, 10 in. diameter, which extends the whole length of the boiler, and is carried outside the brick setting. The branch pipes C C are fixed to each of the sections by a flange, bolted to a corresponding flange upon a short neck cast on the top of the section; and they are connected to the steam main D by a flange.

The expansion of the cast-iron sections when heated does not affect the joints, because in the rear sections the separate castings are connected together by only a single joint at the bottom, and are thus free to expand in any direction without injury. In the front sections the effect of the expansion is to widen the arch to the extent of $\frac{3}{8}$ in.; the arched sections are connected to the first of the rear sections, for the purpose of affording a continuous water way through the whole length of the boiler, but on one side only, so that they are left free to expand and slide upon the brickwork on the other side. The wrought-iron branch steam pipes C, connecting to the steam main D, spring to a sufficient extent to allow for the excess of expansion of the cast-iron sections, without causing objectionable strain on the joints.

The flange joints of the boiler are faced and put together with wire gauze and red lead, so that they can be readily separated and re-made if required; they are finished to a standard template, so that any portion of the boiler can be readily removed and replaced, without disturbing the rest of the sections, which are duplicates. The front sections are all finished to the same length of 11 in. at the bottom joint, and the rear sections to 12 in. length. All the joints are completely protected from the action of the fire. Those at the top are protected by a layer of brickwork which rests upon the castings, as in Figs. 427 and 429; and the rear sections are cast with small projecting ribs upon them, which come together when the sections are fixed in their places, thus forming a close top to the flue. The whole boiler is enclosed by side walls of brickwork, which are carried up above; and the top is covered in with loose cast-iron plates that are readily removed for inspection. A large sight-hole with cast-iron cover-plate is made in one side wall opposite every alternate rear section, which allows of cleaning all the surfaces of the cast-iron tubes from soot and dust, by means of a jet of steam introduced by a flexible pipe into each of the holes in succession; this cleaning is usually done about every other day.

A blow-off cock E is fixed on the front end of each of the two bottom side tubes; the boiler is blown off once a week, and a small portion of the water is also blown off three times in each week. The feed water is introduced at F F, below the fire level; the feed pipe is connected to the bottom main on one side of the fire and also to the first of the rear sections.

The size of the boiler is regulated by the number of sections employed in its construction; and more sections can be added afterwards, without disturbing those previously fixed. The usual size of the boiler, Figs. 427, 428, consists of six front and twelve rear sections, and is equal to about 36 H-P. The effective heating surface of each rear section, taken from the top of the base piece to the centre of the upper chamber, is 23 sq. ft.; and each arched section, taking only the inner half of the surface, is 7 sq. ft.

In trials made by J. Laybourne, of Newport, to ascertain its evaporative power and economy, the cast-iron boiler has proved satisfactory; in one instance an evaporative duty was obtained as high as $11\frac{1}{2}$ lb. of water to the lb. of coal. In this case $625\frac{1}{2}$ gallons of water at 53° Fahr. were evaporated in 3 hrs. 54 mins. by 560 lb. of Ebbw Vale Elled coal, amounting to 11·17 lb. of water to the lb. of coal, and equivalent to 11·67 lb. of water evaporated from 100° standard temperature of feed; the steam pressure was from 55 to 60 lb.

In using the general class of boilers having small water-space, disappointments have been experienced from their not continuing at work without difficulties in keeping them in order; but it cannot be expected that the more complicated and delicate structure of these boilers, can admit of the same rough handling, and marked absence of systematic attention, that so commonly occur with the ordinary cylindrical boilers. Again at the end of a certain period, dependent on the quality of the water used, they must be laid off for cleaning internally, otherwise the tubes would be liable to become choked up. Regularity of firing and steadiness of feed, are also matters requiring stricter attention than in boilers which contain several hours' supply of water.

Plate iron is in many instances replaced by steel in the construction of boilers, the soft steel obtainable from certain processes being peculiarly suited for the purpose. The following particulars of experiments made by William Boyd, of Newcastle-on-Tyne, and presented to the Institute of Mechanical Engineers, in 1878, are therefore of peculiar interest.

Boyd's experimental steel boiler, Figs. 431 to 433, was of the usual marine type, 13 ft. 3 in. diameter by 10 ft. 8 in. long, and contained three furnaces, 3 ft. 3 in. diameter; the working pressure proposed was 65 lb. on the sq. in., and the total heating surface 1880 sq. ft. It is not necessary to refer further to this design than to state the reduction it was proposed to make in the thicknesses of the various plates, which was as follows;—

	Inches.	Reduction per cent.
Boiler shell plates	from $\frac{7}{8}$ to $\frac{11}{16}$	= 21·43
Boiler ends	,, $\frac{3}{4}$,, $\frac{9}{16}$	= 25·00
Furnaces and combustion chambers ..	,, $\frac{1}{2}$,, $\frac{7}{16}$	= 12·50
Front and back tube-plates	,, $\frac{3}{4}$,, $\frac{11}{16}$	= 8 33

On this design being submitted to the committee at Lloyd's, whose requirements were the cause of the experiments being undertaken, it was approved of as an experiment only, provided the material showed the following tests;—

1st. That some of the plates taken indiscriminately from among the shell and other plates should be submitted to a tensile test, and shown to have an ultimate strength of from 26 to 30 tons on the sq. in.

2nd. That a specimen of the riveted longitudinal joint should be tested, and proved to have a percentage of strength at least equal to 74 per cent. of the solid plate.

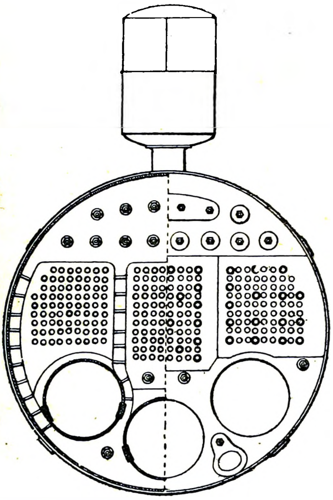
3rd. That a shearing of every plate used in the construction of the furnaces, combustion chambers and tube plates, should be subjected to the tempering tests with satisfactory results. These tests consist in heating the sheared strips to a dull red and cooling them out in water of 82° F., after which they should stand bending over to an external radius of $1\frac{1}{2}$ times the thickness of the plate.

4th. That it should be shown by an actual experiment that the flat plates with the proposed reduction of thickness, stayed in the usual manner, are as strong to resist buckling, by hydraulic pressure, as ordinary wrought-iron plate.

It may be mentioned here that after careful consideration and experiment, of which the details will be given hereafter, it was decided to use steel rivets in the construction of the boiler; and also that it should be fitted with solid-drawn steel tubes, so that the structure might be homogeneous in all its parts.

The first series of tensile tests is that given in Table I.; and the results may be summarised in a few words. Seventeen samples were prepared, but three of these gave way at the attachment, leaving fourteen successful. The average tensile strength of these fourteen specimens is 28·7 tons on the sq. in., and with one exception, No. 7, they exhibit a remarkable uniformity, showing that regularity of quality is now obtainable in a large specification of steel plates without practical difficulty.

431.



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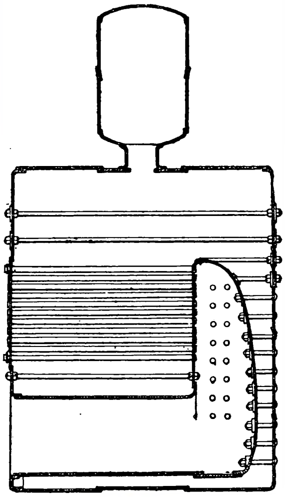
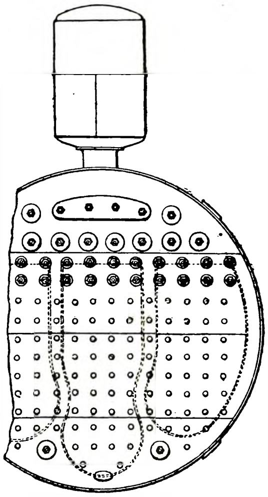


433.



STEEL BOILER EXPERIMENTS (BOYD).

TABLE I.—TENSILE TESTS.

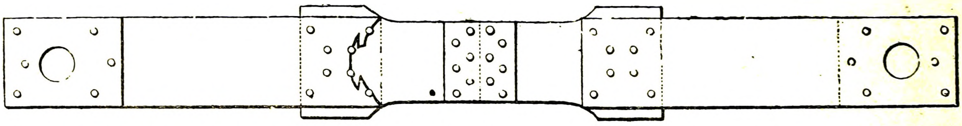
No. of Specimen.	Description of Plate.	Thickness of Plate.	Test Piece.				Stress.				Ratio of Limit of Elasticity to Breaking Stress.	Ratio of Fractured to Original Area.	Stress to the Sq. In. of Fractured Area.	Elongation.				Ultimate Elongation in Percentage of Length.
			Dimensions.	Sectional Area at Line of Fracture.	Length.	Fractured Area.	Actual.		On the Sq. In.					Elongation at Limit of Elasticity.	Commencement of Elastic Stretch.	Amount of Elastic Stretch.	Ultimate Breaking Stress.	
							Limit of Elasticity.	Breaking Stress.	Limit of Elasticity.	Breaking Stress.								
		in.	in. in.	sq. in.	in.	sq. in.	tons.	tons	tons.	tons.	per cent.	per cent.	tons.	in.	tons.	in.	in.	per cent.
1	Centre Furnace Crown	7–16	$1\frac{7}{8}$ × ·453	0·849	$5\frac{1}{8}$	..	16	21·0	18·8	..	..	..	..	·031	12	·01	..	..
2	Ditto	7–16	$1\frac{5}{8}$ × ·453	0·736	$4\frac{1}{4}$	0·546	14	21·5	19·0	29·2	65	74	39·3	·031	10	·01	1·16	..
3	Wing Furnace Crown	7–16	2 × ·468	0·936	$1\frac{7}{8}$	0·694	17	27·5	18·1	29·3	62	74	39·6	·046	16	·031	0·46	..
4	Ditto	7–16	$1\frac{7}{8}$ × ·453	0·849	$1\frac{1}{2}$	0·559	16	26·0	18·8	30·6	61	65	46·5	·031	16	·031	0·51	..
5	Wing Combustion Chamber; Back	7–16	2 × ·437	0·874	$6\frac{1}{2}$	0·536	16·5	25·0	18·8	28·6	66	61	46·4	·046	8	·01	1·50	23·23
6	Ditto	7–16	2 × ·437	0·874	$6\frac{1}{2}$	0·492	16	25·0	18·3	28·6	64	56	50·8	·031	15	·015	1·75	26·9
7	Back Tube-plate	11–16	$1\frac{3}{4}$ × ·702	1·228	12	0·798	17	31·5	13·8	25·6	53	65	39·4	·031	12	·01	3·31	27·6
8	Ditto	11–16	$1\frac{7}{8}$ × ·687	1·288	12	0·691	20	36·5	15·5	28·3	54	53	52·8	·045	9	·015	3·31	27·6
9	Boiler Shell ..	11–16	2 × ·681	1·362	$6\frac{1}{2}$	0·716	20	38·0	14·6	27·9	52	52	53·0	·031	15	·01	1·96	30·1
10	Ditto	11–16	2 × ·687	1·374	$6\frac{1}{2}$	..	20	34·5	..	..	..	..	..	·031	15	·01	..	..
11	Dome Neck ..	9–16	$1\frac{5}{8}$ × ·620	1·007	$5\frac{1}{4}$	0·546	14	28·0	13·9	27·8	50	54	51·2	·031	13	·015	1·68	..
12	Centre Furnace Bottom	7–16	2 × ·437	0·874	$7\frac{1}{4}$	0·468	14	25·5	16·0	29·1	55	53	54·4	·031	11	·015	2·00	27·5
13	Wing Furnace Bottom	7–16	$1\frac{3}{4}$ × ·437	0·764	$7\frac{1}{4}$	0·409	14	23·0	18·3	30·1	65	53	56·2	·031	12	·015	1·78	24·5
14	Ditto	7–16	$1\frac{15}{16}$ × ·437	0·846	$7\frac{1}{4}$	0·458	14	24·5	16·5	28·9	57	54	53·4	·031	11	·015	2·18	30
15	Back End	9–16	$1\frac{15}{16}$ × ·560	1·084	$2\frac{3}{8}$	..	19	31·0	..	..	..	.	..	·016	19	·016	..	..
16	Ditto	9–16	$1\frac{3}{4}$ × ·546	0·955	$2\frac{3}{8}$	0·439	16	30·0	16·7	31·4	53	46	68·3	·031	16	·031	0·62	..
17	Front End	9–16	$1\frac{15}{16}$ × ·619	1·199	$6\frac{1}{2}$	0·641	18	33·0	15·0	27·5	54	53	51·4	·015	15	·01	1·87	28·7

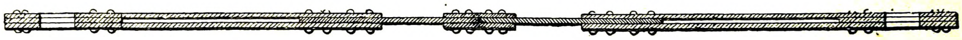
Elasticity is lost at an early point at an average of 16·6 tons a sq. in., equal to 58 per cent. of the average ultimate breaking stran. Elastic stretch also commences early; for in specimen No. 9, taken from the shell plates of the boiler, it is seen that elastic stretch is perceptible at a strain of 15 tons, equal to 11 tons a sq. in. of section. The strain on each sq. in. of the longitudinal joint, when the boiler is under the hydraulic test of double the working pressure, is 9·22 tons a sq. in., leaving a margin of $1\frac{3}{4}$ tons a sq. in., which is sufficiently small to point to the advisability of not submitting a steel boiler to a greater hydraulic test than twice the working pressure.

In endeavouring to arrive at a fair estimate of the amount of stretch in relation to the length, it was thought advisable to eliminate all the short specimens as not affording reliable data. Taking four specimens $6\frac{1}{2}$ in. long, three $7\frac{1}{4}$ long, and two 12 in. long, nine in all, it is seen from the last column in Table I that the average ultimate stretch or elongation is 26·5 per cent. of the length of the specimens, which is a considerable amount, and will be further referred to hereafter.

The experiments on the longitudinal joints were instituted in order to determine their strength, which had been calculated to bear a strain of 73·41 per cent. of the solid plate. Two samples were prepared, Figs. 434 to 437, representing a fair average portion or strip of the longitudinal seam, 12 in. broad × $\frac{11}{16}$ in. thick, the area of which through the solid plate is equal to 8·25 sq. in. The rivets were $1\frac{1}{16}$ in. diam., pitched 4 in. apart from centre to centre. The holes in the joint, where the specimen was expected to give way, were drilled through the butt straps and plates, as would be done in practice; but the work of the attaching plates was put together without sufficient consideration, and the holes were punched and closed by iron rivets in the ordinary way.

434.





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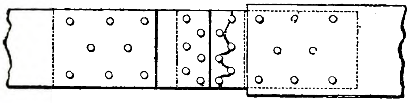
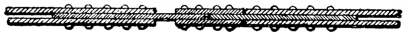
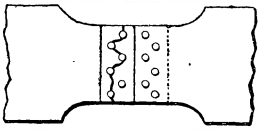
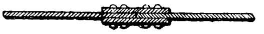




437.

438.





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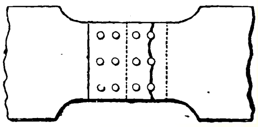
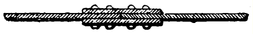
440.





441.

On being tested, the specimen broke at the attachment joint, in the line, Fig. 434. The breaking strain was 135 tons, equal to 18·51 tons a sq. in., with little or no elongation. The area at the point of fracture was 7·29 sq. in.; whereas at the point where the fracture was expected to occur, in the line of rivets of the longitudinal seam, the area was only 6·057 sq. in., and the holes closer to each other.

Specimen No. 2 was a duplicate of No. 1, so far as the joint was concerned, and broke through the line of rivets, as shown in Fig. 436, with a strain of 149 tons, equal to 24·59 tons a sq. in. on a net sectional area of 6·057 sq. in.

These results were not considered wholly satisfactory. Two other specimens were therefore prepared, Nos. 3 and 4, Figs. 438 to 441. No. 3 was an exact duplicate of Nos. 1 and 2 in the arrangement of the riveting of the longitudinal joint; but the specimens were both made of sufficient length to avoid altogether the necessity of any attaching plate. In No. 4 chain riveting was employed. Specimen No. 3 gave way with a total strain of 140 tons through a sectional area of 6·057 sq. in., equal to 65·32 per cent. at 26 tons for solid plate, or to 60·66 per cent. at 28 tons. No. 4, though the riveting was arranged on the chain system, had a sectional area of solid plate equal to 8·25 sq. in. and an area through the line of rivets of 6·057 sq. in., giving a percentage of 73·41, and thus being in this respect exactly identical with the other three specimens arranged on the zigzag system. It gave way with a total strain of 174 tons, equal to 81·11 per cent. at 26 tons for solid plate, or to 75·32 per cent. at 28 tons.

These results confirmed the opinion that the cause of failure of the first three specimens was to be found in the narrow strips at the edges.

In all three specimens the joint was considerably stretched before fracture occurred, even in the case of the specimen No. 1; and it would seem that these joints if made in steel would stretch very considerably, and relieve the pressure in the boiler long before it might actually

Table I.—Punched and Drilled Holes in Steel Plates, First Series.

No.	Description of Holes.	Size of Plate.	Sectional Area.	Diameter of Holes.	Breaking Stress, Total.	Breaking Stress, a sq. in.	Mean Breaking Stress, a sq. in.
		in. in.	sq. in.	in.	tons.	tons.	tons.
1	Punched	$8\frac{3}{64} \times \frac{11}{16}$	3·98	$1\frac{1}{8}$	75	18·8	18·1
2	,, ...	$8\frac{3}{64} \times \frac{11}{16}$	3·98	$1\frac{1}{8}$	70	17·4	
3	Drilled	$8\frac{1}{32} \times \frac{11}{16}$	4·01	$1\frac{3}{32}$	110	27·4	27·4

Three experiments on punched and drilled holes are given in Table II. The first two were punched holes, and show a mean breaking strain of 18·1 tons a sq. in.; taking 28 tons a sq. in. as the breaking strain of solid steel plate, this shows a loss of strength equal to 35·36 per cent. In the third experiment the holes were drilled, and the specimen broke at 27·4 tons per sq. in., showing a loss of strength of only 2·15 per cent.

Table III.—Punched and Drilled Holes in Steel Plates, Second Series.

No.	Description of Holes.	Size of Plate.	Sectional Area.	Diameter of Holes.	Breaking Stress, Total.	Breaking Stress, a sq. in.	Mean Breaking Stress, a sq. in.
		in. in.	sq. in.	in.	tons.	tons.	tons.
1	Punched	$8 \times \frac{13}{16}$	4·72	$1\frac{3}{32}$	103	21·8	21·15
2	"	$8 \times \frac{13}{16}$	4·72	$1\frac{3}{32}$	97	20·5	
3	" (annealed)	$7\frac{15}{16} \times \frac{13}{16}$	4·70	$1\frac{3}{32}$	142	30·2	29·5
4	" "	$8 \times \frac{13}{16}$	4·72	$1\frac{3}{32}$	136	28·81	
5	Drilled	$8 \times \frac{13}{16}$	4·72	$1\frac{3}{32}$	146	30·9	30·9

Table III. exhibits the result of experiments to ascertain whether the process of heating, or annealing, the plates in the furnace had any effect; for in practice all the shell plates were so treated, being put into a plate furnace and heated to a dull red heat, before being bent in the rolls to the required diameter. The first two specimens had the holes punched, and broke at a mean strain of 21·15 tons a sq. in. In the second pair the holes were also punched, but the specimens were afterwards annealed in the manner described, and the mean breaking strain rose to 29·5 tons a sq. in., showing a result fully equal to that allowed a sq. in. for solid plate. In the fifth plate the holes were drilled and the breaking strain was 30·9 tons a sq. in. If then the mean breaking strain of these last three specimens be taken as 30·2 tons a sq. in., and the breaking strain of the first two specimens with punched holes as 21·15 tons a sq. in., a loss of 29·97 per cent. is shown in this plate, all the five samples having been cut out of one plate, as being due to the operation of punching the holes.

The result of the whole of these experiments seems to show conclusively that this material is not injured by drilling; that it is injured to the extent of about 33 per cent. by punching; but that the nature of the material is restored entirely, if the plate be heated and annealed after punching, and allowed gradually to cool out.

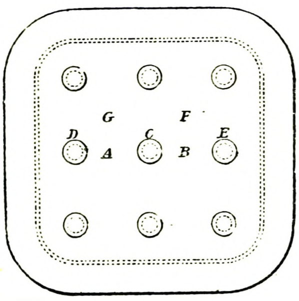
Experiments were made to ascertain whether the steel rivets were likely to be rendered brittle, by being heated in the furnace, and then cooled by the application of the pressure of the hydraulic riveter.

The rivet heads from two similar rows of rivets, put in a lap joint in the usual way, but one row of iron and the other of steel, were cut off by the repeated blows of a hammer on the head of a blunt set held against the rivet head, in the ordinary way when the head of a defective rivet has to be removed; the same hammer was used throughout, weighing 11 lb.; the same two men struck the blows turn and turn about; and they cut an iron and a steel rivet alternately. The steel rivets were made from bars of Landore-Siemens steel, the same quality as the boiler plates; and the iron rivets were made of best scrap iron. The result was that the steel rivets 1 in. diameter stood an average of 16 blows each as against 10 for iron, or 60 per cent. higher average, and the $\frac{3}{4}$-in. steel rivets stood an average of 6 blows as against 3·5 iron, or 71·4 per cent. higher average.

This result decided the point that steel rivets should be employed; and they were heated in an open-hearth rivet-heating furnace, arranged so that the flame would not burn them, while they were all heated to a uniform temperature. The riveting was done by hydraulic riveters, giving a pressure of 40 tons on the rivet head.

Buckling tests were first made without nuts on stays. Two boxes were constructed, as in Figs. 442, 443, and subjected to increasing hydraulic pressure. One box was made of iron, with plates $\frac{1}{2}$ in. thick, and the sides were held together with nine screwed stays of iron, $1\frac{1}{2}$ in. diameter, 9 in. apart, with the heads riveted over in the usual way, and having 10 threads to the inch. The other box was made of steel plates $\frac{7}{16}$ in. thick, held together by screwed stays of steel, $1\frac{3}{8}$ in. diameter, 9 in. apart, with the heads riveted over in the same way as the iron ones, and screwed to the same pitch.

442.



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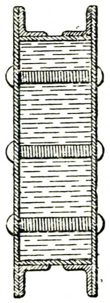

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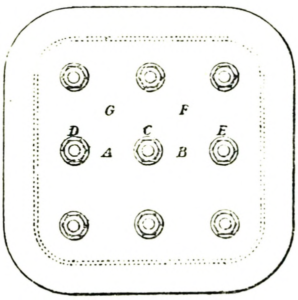

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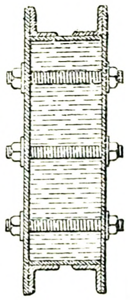


The buckling was carefully noted at the several points marked A to G in Fig. 442. The result are given in Table IV. as being fair places at which to institute comparison. Attention may be drawn to the fact that in the steel plates the buckling commenced at 130 lb. pressure a sq. in., whereas it did not commence in the iron plates till 195 lb. Permanent set took place in the steel plates at 325 lb., and in the iron at 390 lb. At 422 lb. the buckling at the points A and B, was eight times greater in the steel plates than in the iron plates, and at the same pressure was nearly four times greater at the points F and G. The ultimate bursting point occurred in each case at the centre stays, with a pressure of 550 lb. a sq. in.

Table IV.—Buckling Tests without Nuts on Stays.

Iron Box.

Point marked in Fig. 442.	Internal Pressure, Lb. a Square Inch.							
	lb. 65	lb. 130	lb. 195	lb. 260	lb. 325	lb. 390	lb. 422	lb. 475
	in.	in.	in.	in.	in.	in.	in.	in.
Left-hand side, A	0	0	·015	·015	·015	·062	·079	..
" " B	0	0	·015	·015	·015	·077	·095	..
" " C	0	0	0	0	0	0	Bare	..
Right-hand side, A	0	0	0	0	Bare	·015	·046	·250
" " B	0	0	0	0	·031	·047	·062	·235
" " C	0	0	0	0	0	0	0	0
" " D	0	0	0	0	0	0	0	·062
" " E	0	0	0	0	0	0	0	0
" " F	0	·015	·031	·031	·046	·063	·093	·250
" " G	0	0	·015	·015	·045	·093	·124	·406

Permanent Set at 390 lb. a square inch. Burst at 550 lb. a square inch.

Steel Box.

Point marked in Fig. 442	Internal Pressure, Lb. a Square Inch.							
	lb. 65	lb. 130	lb. 195	lb. 260	lb. 325	lb. 390	lb. 422	lb. 475
	in.	in.	in.	in.	in.	in.	in.	in.
Left-hand side, A	0	·015	·015	·046	·062	·407	·750	·750
" " B	0	0	0	·015	·062	·375	·704	·718
Right-hand side, A	0	·015	·031	·046	·078	·296	·390	·421
" " B	0	·015	·031	·031	·077	·312	·437	·454
" " C	0	·015	·015	·015	·031	·077	·077	·077
" " D	0	0	0	0	·015	·046	·046	·031
" " E	0	0	0	0	0	·046	·046	·046
" " F	0	·031	·031	·046	·093	·390	·406	·406
" " G	0	·031	·031	·046	·093	·281	·408	·531

Permanent Set at 325 lb. a square inch. Burst at 550 lb. a square inch.

Table V.—Buckling Tests with Nuts on Stays.

Iron Box.

Point marked in Fig. 444.	Internal Pressure, Lb. a Square Inch.											
	lb. 65	lb. 130	lb. 195	lb. 260	lb. 325	lb. 390	lb. 455	lb. 520	lb. 585	lb. 650	lb. 715	lb. 780
	in.	in.	in.	in.	in.	in.	in.	in.	in,	in.	in.	in.
Left-hand side, A	..	..	..	..	..	·031	·031	·062	·062	·062	·187	·575
" " B	..	..	·015	·062	·062	·062	·062	·062	·125	·125	·250	..
" " C	..	..	..	..	..	..	..	..	·015	·015	·015	·015
" " D	..	..	..	·015	·015	·015	·015	·015	·015	·031	·062	·093
" " E	..	..	..	·031	·031	·031	·031	·031	·031	·031	·031	·062
Right-hand side, A	..	..	..	..	..	..	..	·015	·015	·062	·125	·344
" " B	..	..	..	..	·031	·031	·031	·046	·046	·093	·156	·375
" " C	..	..	..	..	..	..	..	..	..	·015	·031	·125
" " D	..	..	..	..	..	..	..	..	..	..	..	..
" " E	..	..	..	..	..	..	..	..	..	..	..	·031
" " F	..	..	..	..	·015	·062	·062	·077	·094	·125	·187	·375
" " G	..	..	..	..	..	..	·015	·031	·062	·125	·187	·375

Permanent Set at 585 lb. a square inch. Burst at 1000 lb. a square inch.

Steel Box.

Point marked in Fig. 444.	Internal Pressure, Lb. a Square Inch.										
	lb. 65	lb. 130	lb. 195	lb. 260	lb. 325	lb. 390	lb. 455	lb. 520	lb. 585	lb. 650	lb. 715
	in.	in.	in	in.	in.	in.	in.	in.	in.	in.	in.
Left-hand side, A	..	..	·015	·031	·062	·062	·187	·25	·375	·468	·500
„ „ B	..	..	·015	·031	·062	·062	·187	·25	·406	·499	·562
„ „ C	..	..	..	..	..	..	..	..	..	..	..
„ „ D	..	..	..	..	..	·015	·015	·015	·031	·062	·062
„ „ E	..	..	..	..	..	·031	·046	·062	·062	·093	·093
Right-hand side, A	..	..	..	·015	·031	·062	·056	·250	·344	·437	·625
„ „ B	..	..	·031	·031	·062	·093	·218	·281	·375	·500	·656
„ „ C	..	..	..	..	..	..	·015	·031	·031	·062	·093
„ „ D	..	..	..	..	..	..	·031	·031	·031	·093	·156
„ „ E	..	..	..	..	..	..	..	..	..	·031	·062
„ „ F	..	..	·031	·031	·031	·093	·218	·265	·407	·531	·656
„ „ G	..	..	..	..	·094	·156	·279	·375	·437	·562	·625

Permanent Set at 390 lb. a square inch. Burst at 900 lb. a square inch.

This early buckling of the steel plates showed the advisability of fitting the heads of the stays with nuts, which was adopted in the case of this boiler.

In order to ascertain exactly the value of these nuts in supporting the flat surfaces, two other boxes were made, identical in every way with the former pair. These are shown in Figs. 444, 445; and the results of the experiment in Table V.

In the steel plates the buckling commenced at 260 lb., and in the iron plates at 390 lb. Permanent set took place in the steel plates at 390 lb., and in the iron at 585 lb. At 585 lb. the buckling of the steel plates at the points A and B was six times greater than in the iron plates; and at the same pressure was six times greater at the points F and G. Finally, the ultimate bursting occurred in the case of the iron box at a pressure of 1000 lb. a sq. in., the fracture taking place in the L iron and the framework of the box generally. Some of the nuts on the stays were cracked, but none of the screwed stays broke; nor did the flat plates give way at any part. In the case of the steel box the bursting occurred at 900 lb. a sq. in., and as in the iron one it was the general framework that gave way. None of the stays broke, nor did the flat steel plates crack at any point.

As a test of the effect of annealing, a piece of steel plate about 18 in. square was cut into two portions. One portion was heated in the plate-bending furnace to a dull red heat, and then cooled out suddenly in water; this process was repeated fifty times. The two pieces were then punched, bent cold and experimented on in various ways, with the result that the piece which had been subjected to this fifty-fold annealing process had lost none of its nature, but was as ductile and malleable as the other piece of plate which had not been so treated.

Stationary Boilers should be set with as little brickwork in contact with the shell as practicable, particularly at and near the bottom, where any water or moisture is liable to lodge against the plates. All the flues should be faced with fire bricks, and fire lumps or blocks, but not bricks, should be used for the seating. No mortar should be used where it can come in contact with the plates, but fireclay should be used instead for the whole setting of the boiler. The flues should be sufficiently large to admit of being properly cleaned and to enable periodical external examinations to be made with facility and satisfaction. The common practice of cramping the flues arises out of the desire to improve the efficiency of the boiler by keeping the gases in contact with the plates. But the slight waste of heat that may result from the use of moderately wide flues, is far outweighed by the greater security obtained from the better examination they invite. These instructions and some of those which follow are given by J. Wilson in his capital little treatise on Steam Boilers.

Plain cylindrical or egg-ended boilers, when made with wheel draught or split draught, are supported on side walls, which should not exceed 3 in. in width at the surface on which the boiler rests. There is, however, no advantage gained in evaporative effect by making the flues of long and moderately long egg-ended boilers for wheel draught or split draught; but there is a decided disadvantage in the increased difficulty of cleaning and examining which these arrangements of flues involve. These boilers are best set with flash flues, the gases passing straight from the bridge along the boiler bottom and sides to the chimney. This arrangement dispenses with all brick work seating underneath the boiler, which is sometimes supported on cast-iron brackets, protected on their fronts by firebrick, but far more usually by brackets riveted to the sides and resting upon the masonry. Boilers of great length, 50 ft. and upwards, are often suspended from transverse cast-iron arches resting on the masonry at the sides and placed from 12 ft. to 16 ft. apart. The boiler is connected to each bearer by means of three bolts, secured to angle or T irons riveted to the shell crown, and secured to the casting by nuts, by which the weight of the boiler can be adjusted. There should also be a strut of T iron across the inside of the boiler, under each bearer, to resist the tendency of the shell to assume an oval shape, from the weight of the lower portion of the boiler and the water, acting against the upward direction of the force exerted by the suspension bolts.

Since the weight on each bearer must vary considerably with the arching of the shell, due to the greater expansion or contraction of the bottom compared with the top, long boilers are liable to be strained and break their backs, when suspended from the end attachments only, or the bottom is liable, to become buckled together, when suspended only from the middle bearers.

To obviate this, J. Head devised a plan of suspending very long boilers by means of rings, hanging by springs or counter weights on suitable pillars; this has met with some success.

The typical Lancashire boiler, Fig. 386, is set on side walls, and rests on firebrick seating blocks presenting a bearing surface 5 in. wide, Fig. 388. The side flues are 6 in. wide at the top, carried up to the level of the furnace crowns, or a few inches above, and down to the level of the bottom of the shell. The bottom flue has a width equal to the radius of the boiler, and a depth of about 2 ft. These dimensions admit of ample room for inspection. By keeping the width of the bottom flue equal to the radius of the boiler, the angle that the bearing surface of the seating block makes with the horizon is 30° for any diameter of shell.

The flame immediately after leaving the furnace-tubes passes under the bottom of the boiler, and returns to the chimney along the side flues. This is not the course approved by Pole in his treatise on the Cornish Pumping Engine published in 'Tredgold on the Steam Engine' in 1844, in which the setting of the Cornish boiler is spoken of as follows;—"The heated current first impinges on the top of the tube, over which the highest and therefore the hottest portion of the water is lying; it then passes along the side flues, where it finds the surfaces cooler than before; and last of all it traverses under the bottom of the boiler, where the coldest water will always be. By this means the fire current, as it gradually cools, is likewise gradually brought to act upon cooler water, and thereby the best opportunity is afforded for the extraction of the free caloric it contains. . . . . The descending motion of the fire current, as it cools in the flues of the Cornish boiler, is upon statical principles much more natural, and more calculated to prevent the unnecessary discharge of heat into the chimney than the ascending principle of the ordinary boilers." Allowing the last heat, however, to travel under the bottom of the shell does not promote the circulation of the water, or at all events but slowly; so that in getting up steam the top of the boiler becomes hotter than the bottom, from which straining ensues. If, in addition to this, the feed water when cold is pumped in at, or near the bottom of the boiler, the straining at the transverse seams of rivets is intensified. Possibly the Lancashire boiler is more subject to straining and seam-rending at the bottom of the shell than the Cornish, as there is a greater body of dead water lying there in the Lancashire boiler, in addition to which the rate of combustion on each sq. ft. of firegrate, is much more rapid in the Lancashire district than that generally adopted in Cornwall. In consequence of seam rents occurring at the bottom of Lancashire boilers when the last heat is carried underneath, the plan of passing the flame under the bottom immediately on leaving the furnace-tubes, and also of introducing the feed water near the surface, has become the general practise. Feed-water heaters, consisting of a number of water pipes placed in the main flue between the boiler and the chimney, and kept free from soot by an automatic scraper, are in general use. A good feed heater will raise the temperature of the water to about 240°. This economises the heat escaping to the chimney and thus reduces the coal consumption, while at the same time it prevents local cooling. It has been found by experiment that passing the flames from the furnace tubes around the outer shell, instead of direct to the chimney, adds but little to the yield of steam, though it promotes economy of fuel; at the same time it keeps the boiler at a more equable temperature throughout.

The flooring or hearth plates at the front of the boiler are set so as not to butt against the boiler, but so as to be entirely below it, as in Fig. 387, thus leaving the whole of the front end plate open to view. Where there is a range of boilers, these flooring plates extend throughout the width of the boiler house; being finished off with a fender-flange where abutting against the boundary walls of the building, as well as against the face of the brickwork setting. These plates are carried on a complete system of framing, and are arranged for easy lifting. The hearth pit beneath them is open from one side of the boiler house to the other, and in this is laid the main feed-pipe, as well as the discharge pipe from the blow-out and scum. This pit is about 3 ft. wide by 2½ ft. deep, so as to afford room for access; the flue doors open into it. The face of the brickwork at the front of the boilers is set back 6 in., so as to leave the angle-iron with its circle of rivets perfectly open. The front cross wall beneath the boiler is recessed around the blow-out elbow-pipe, that it may be free to move should settlement of the boiler take place.

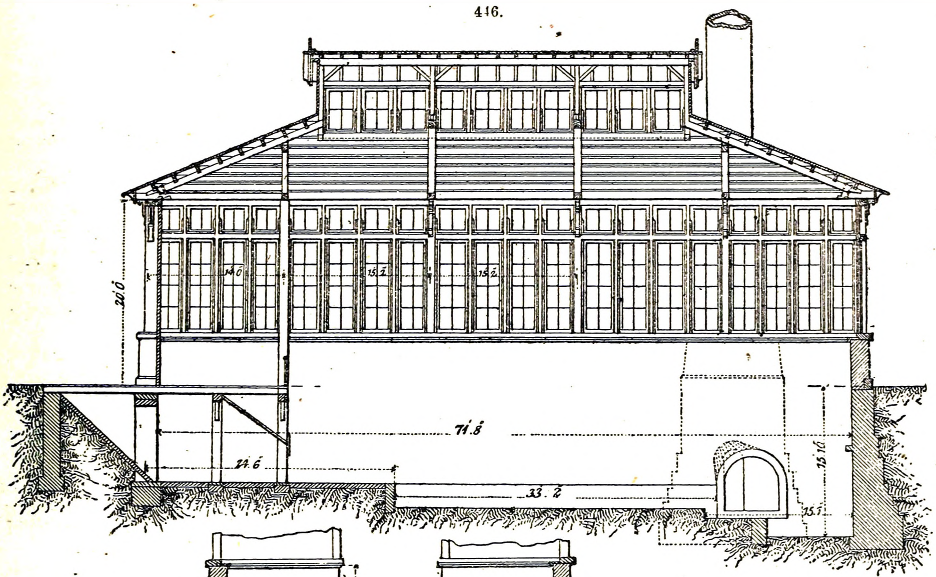
The boiler is covered with an arch of brickwork, leaving a space of about 2 in. between it and the plates, Fig. 388; and a layer of cork shavings, or a coating of other suitable non-conducting substance, is introduced into this space. Openings finished off with bull-nosed bricks are worked round the fittings, leaving the ring of rivets by which they are attached to the shell exposed to view. Sometimes the boiler is covered simply with a layer of composition, which should not be carried over the flanges of the fittings, as is too often the case, but be stopped off by means of kerb hoops dropped around the flanges, and a kerb cast iron nosing to guard the front angle-iron.

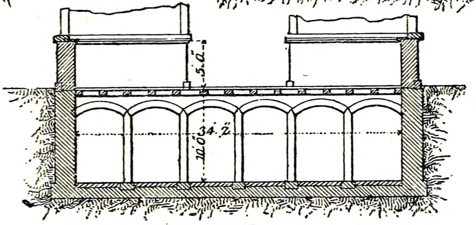
Each side flue may be made with an independent damper, or one damper may be made to serve by uniting the side flues behind the down-take at the back. But when the boiler is very short compared with the length of grate and there is a strong draught, it is not always advisable to expose the shell bottom to a very high temperature, by taking the gases along the bottom before passing through the side flues.

In setting such a boiler as is that in Figs. 383 to 385, a foundation is first formed and covered with one thickness of firebrick, forming the base of the bottom flue; on this are placed cast-iron supports for the boiler to rest upon, these being hollow and so formed as to be of the same outline as the flue, and so as not to interfere with its proper cleaning. The side walls of the bottom flue are next commenced, and the boiler fixed on the cast-iron supports, after which the side flues are built up to the boiler. In all cases it is well to line the flues with 4½ in. of firebrick up to the base of the chimney. The bottom flue is made very large, in order that a workman may be enabled to get in to clean it. After the brickwork has been carried up to the height of the side flue arches, the remaining part of the boiler is covered with very fine ashes; in many instances the ashes are made to cover the top of the boiler, to such a depth that only the lids of the stop valve and the safety valve remain uncovered. This is so effective that the temperature of the top of the ashes has been found to be only 90°, when that of the boiler has been 270°. An advantage attending the use of ashes as a non-conducting material, is that they admit of ready removal for the purposes of inspection or repair.

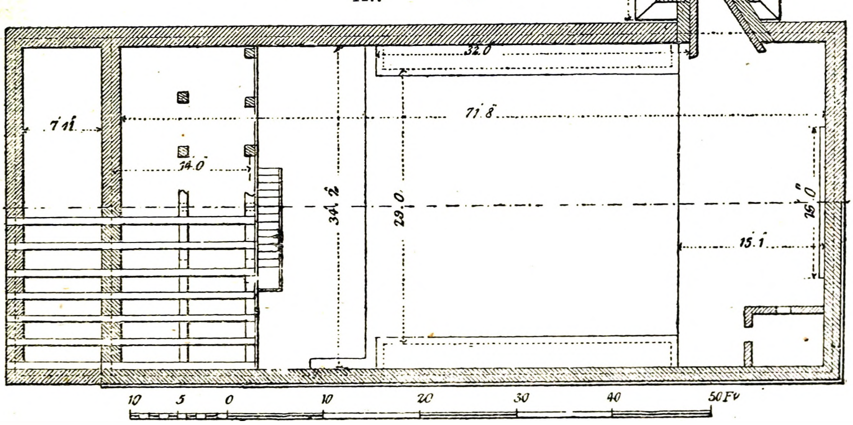
The Figs. 446 to 450 afford a good example of the arrangement of a boiler house, and refer to the building erected for boilers exhibited by English firms at the Philadelphia Exhibition in 1876, the walls being of stone for a height of 5 ft., and above that of open framework filled in with glass, with a timber roof covered with tin and crowned with louvre ventilators, the side sashes swinging on centres; this would, of course, be replaced by a roof of the usual material in a permanent structure. It is provided with a vault with inclined shoot, Figs. 446, 448, extending out under the railroad track, to facilitate putting in coal from drop-bottom cars. Over the coal vault at the entrance door is a platform, level with the exterior surface of ground, extending into the building, and protected by an iron railing on the sides.

446.





447.

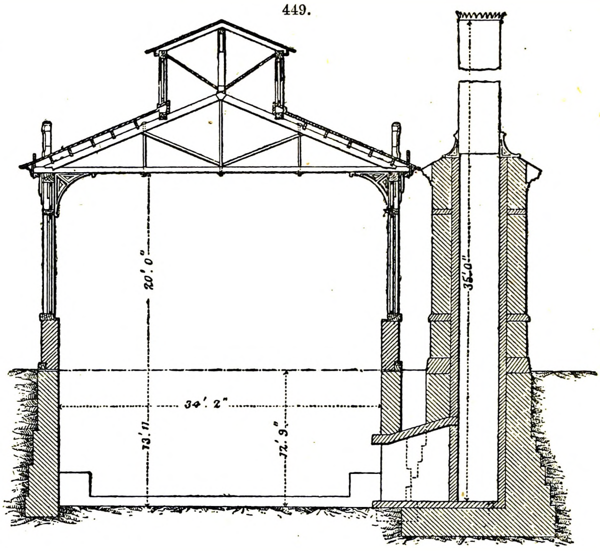


448.

The house covers an area of 36 ft. by 73½ ft., measured to centre lines of walls; the longitudinal dimension being at right angles to the main hall.

At one end the space for a distance of 24½ ft. is sunk to a depth of 10 ft. below the ground surface, and the remainder, where the boilers are to be placed, to a depth of 12 ft. 9 in., except at the rear of the building, where for a width of 9 ft. the depth is 15 ft. 10 in. The space in front of the boilers, including the portion for fuel, is covered with a broken stone concrete floor 6 in. in thickness.

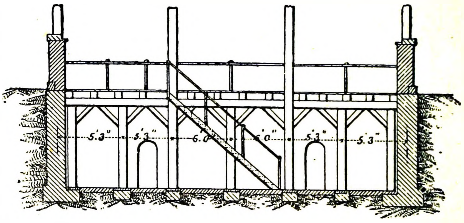
449.



The building has one chimney, Fig. 449, which has a stone foundation 15½ ft. square, resting on two horizontal courses of timber 17 ft. below the surface of the ground, the stone finish continuing to the height of the stonework of the walls of the building, above which it is of brick to the level of the eaves. On this is a wrought-iron chimney, 4 ft. 3¼ in. in diameter and 56 ft. high, stayed with wire guys, the total height from bottom of flue to top of pipe being 92 ft. The circular brick flue of the base is lined, 9 in. in thickness, with firebrick. It is designed to contain three cylindrical boilers, each 28 ft. long by 7 ft. in diameter, with two furnaces, each 2 ft. 9½ in. in diameter by 7 ft. 6 in. long.

List of Books on Boilers.—Burgh (N. P.), 'Practical Treatise on Boilers and Boiler Making,' 4to, 1873. Sexton (M. J.), 'Pocket Book for Boiler Makers,' 32mo, 1875. 'Reports of the Admiralty Committee on the Deterioration of Boilers,' fol., 1876, 1877. 'Proceedings of the Institution of Mechanical Engineers,' 1870 to 1877. 'Transactions of the Institution of Naval Architects,' 1877. Wilson (R.), 'Treatise on Steam Boilers,' crown 8vo, 1879. 'Engineer,' 1870 to 1878. 'Engineering,' 1870 to 1878. Poillon (L.), 'Cours théorique et pratique de Chaudieres et de Machines à Vapeur,' 4to, 1877.

450.



BRAKE.

The application of brake-power has become of the highest importance as affecting the working of railways and the safety of the travelling public. The subject has by no means received the attention it not only deserves but demands. That so many lives should be risked, and so high a percentage lost on most of our railways, is mainly due to the neglect of utilizing an efficient system of brakes, and it is essentially necessary that these systems should find extended practical application, in order that their merits and demerits may be fully known. The only brake-power formerly employed consisted of hand screw-brakes upon the tender and the guards' vans, but the retarding force produced is so small in proportion to the momentum of the train, that it is not sufficient to arrest the progress of the train in time of danger. It has become necessary to provide, by the use of continuous brakes, the means of arresting trains in short distances. A continuous brake is one by which brake blocks are applied to all, or nearly all, the wheels of the train, and it is the means employed for putting the requisite pressure upon the blocks, that constitute the chief distinctions in the various systems.

There are two different methods of applying brake-power;—

The simple or direct-acting method, including all brakes in which the power is created at the time of putting the brakes into operation. The efficiency of this class of brakes depends entirely upon the good working order of the mechanism employed.

The automatic method, including all brakes in which the power is maintained in readiness to be applied as wanted.

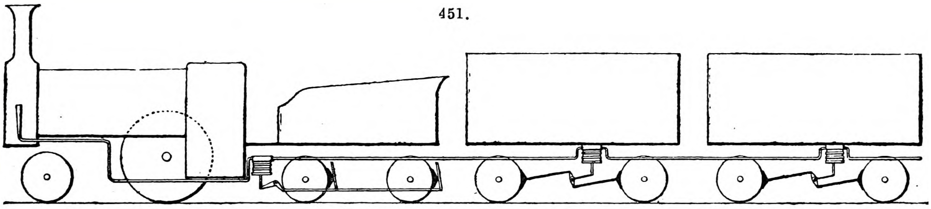
The screw brake has been illustrated at p. 585 of this Dictionary, and consists of a shaft extending from one carriage to another, the revolutions of which screw up the brakes upon the carriages to which it is applied. The shaft is worked by means of hand gearing in the brake vans. It may be considered as an extension of the old hand system, by converting the carriages into so many brake vans. It is evident that, to enable the guard to exert his power effectively throughout a train of say 200 tons weight, a considerable amount of gearing would be required to multiply the power, to the extent sufficient for forcing the blocks against the wheels. This gain of power can be effected only at the expense of time, the most important element in danger.

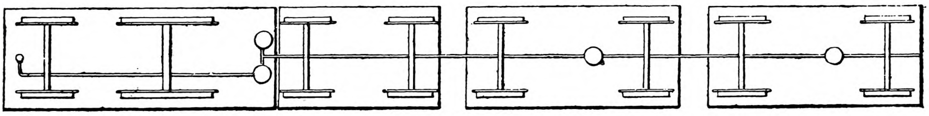
The chain brake, represented at p. 585 of this Dictionary, consists of a chain running underneath the carriages, one end of which is secured to the end of the furthest carriage upon which it is required to exert its influence, and the other to a revolving shaft on the brake van. This shaft carries a friction drum, which being put into motion winds up the chain, raises the levers on each carriage, and applies the brakes. On the axle of the brake van is also a friction drum, and to apply the brakes the two drums are brought into contact, which causes the chain to be wound up on the shaft, and the brakes to be applied. This brake is capable of very quick application. In application it has been customary to extend the chain only to a certain number of carriages at each end of the train, and to place these carriages under the separate control of the front and rear guards. The chain brake can be applied by the driver, and made to act automatically on the two different portions of the train, by means of a cord communication. Upon the train accidentally separating, the cord would be put into tension, and the drums brought into contact; but should the division occur between any of the carriages connected by the chain, the brakes on that portion would not be applied. If the chain were extended the whole length of the train, the brakes could not act automatically in the event of the train separating, although the levers would be released by the breaking of the cord, because the chain would become loose, and the friction pulleys would have nothing to tighten against. In the application of this principle it therefore appears necessary to divide the train into portions, so that the whole power may not be lost by accidental breaking of the chain.

Another form of chain brake is constructed on the principle of keeping the chain constantly under tension, and levers or springs are employed to apply the brakes. The brakes are applied by relaxing the chain, and automatic action is obtained by the breaking of the chain in any part of its length. This method requires some means of winding up the chain and keeping it in tension, and this has been done by means of a winding-up apparatus in the brake vans. It would be difficult to apply such an apparatus on each carriage, so as to be conveniently worked when the brake van was not available, and at the same time to provide for the free control of the chain from the vans, when the train was complete.

The simple vacuum brake, as described by R. D. Sanders in a valuable paper read before the Institution of Mechanical Engineers, 1878, Figs. 451, 452, consists of a continuous pipe extending the length of the train, and connected to collapsing cylinders on each carriage. The heads of the collapsing cylinders are attached to the brake gearing, so that when the air is withdrawn and the pressure of the external air causes them to collapse, the levers are acted upon with a power proportionally to the areas of the cylinder heads and to the degree of vacuum. The end of the continuous pipe on the engine is connected to an ejector, which is supplied with steam from the locomotive boiler; and the end of the pipe at the rear of the train is closed. When the steam is turned into the ejector, the air is drawn out of the continuous pipe, and also out of the collapsing cylinders, and the brakes applied with a power proportional to the vacuum created within the collapsing cylinders. In order to release the brakes, the ejector is shut off and air admitted into the continuous pipe, the collapsing cylinders are relieved of the atmospheric pressure, and rendered inoperative.

451.





452.

The efficiency of this brake depends upon the power of the ejector; and it can be put under the control of the guards as well as of the driver by a cord. This cord communication can be used safely only when the train is intact. In the event of an accidental separation, this would be a source of danger; for the steam cock would be opened by the breaking of the cord, the front portion of the train arrested by the partial application of the brakes, and the rear portion retaining its momentum would run into the fore part.

As the power-producing apparatus is on the engine, in any separation of the train the brake cannot act automatically, without some other exhausting apparatus in the brake vans or on the carriages. This has been supplied by means of exhausting pumps worked from the axles, which, being put into gear by the breaking of the cord or otherwise, withdraw the air from the continuous pipe and so apply the brakes, requiring, however, each pipe-coupling between the carriages to be provided with self-closing valves, otherwise the necessary vacuum could not be created by the exhausting pumps. The automatic action of this brake depends upon the perfect closing of these valves, and upon the efficient working of the pumps, which at 60 miles an hour would make no less than 440 double strokes a minute with 3 ft. 6 in. wheels; and it may be doubted whether the valves and pumps could always be kept in perfect working order, so as to be depended upon with that certainty which is required for an efficient continuous brake. The rapidity of application depends upon the power of the ejector; but under most favourable circumstances, a certain time must elapse in abstracting the air from the pipe and cylinders. The brakes are less effective when the speed is great than when the speed of the train has diminished. This is obviously the reverse of what it should be. In order that the brakes may be applied at all, it is necessary for the continuous pipe to be at all times air-tight. If a pipe-coupling is disconnected, the brakes can be applied with a force due only to the friction of the steam from the ejector against the air passing through the length of pipe which remains unbroken, so that, if a leakage should take place in the front part of the train, the brakes would be useless.

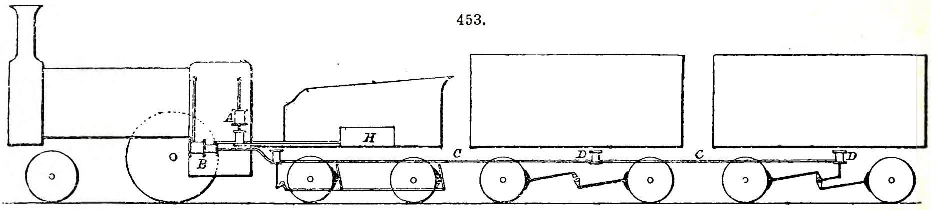
In the application of continuous brakes, the question arises whether the power should be placed in the hands of the driver or of the guards, or of both; and it has to be decided whether a brake should be automatic in its action. The driver, from his position on the engine, is constantly on the look-out ahead. He therefore is the first to be aware of any obstruction on the line, and is in the most favourable position for applying the brakes in time of danger. This should be done simultaneously with shutting off steam, so as to save every available instant of time. If the application of the brakes is entrusted to the guards, much valuable time is lost by the driver having to call attention by means of a cord communication or whistle.

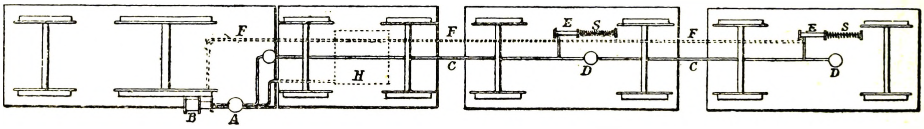
Much time is saved by the driver having full control of the retarding power, as well as of the motive power, instead of relying upon the guards acting in concert with him, in which there is necessarily much uncertainty, their attention being often taken up by other duties. Circumstances may arise which require immediate action on the part of the guards, independently of the driver, such as an axle breaking, a carriage leaving the rails, or a signal from a passenger, and the guards should have the means of applying the whole of the brake-power whenever necessary; but the general working of the brakes should be entrusted to the driver. The conditions necessary to a good system of brakes are;—Complete control throughout the train by the driver; control in time of danger by either of the guards; automatic action in the event of an accidental separation of the train; the brakes to be their own tell-tale in the event of any derangement of the apparatus.

These four conditions are not completely fulfilled in either of the brakes described, but are more nearly met by the following constructions.

The hydraulic brake, Figs. 453 and 454, consists of a continuous pipe throughout the train, connected to a cylinder and piston operating in each carriage upon the brake-blocks. Upon the engine is a steam pump A, which forces the water into an accumulator B. The accumulator consists of two cylinders and pistons, the area of one being double that of the other. The continuous pipe and steam pump are connected to the smaller cylinder, and steam is admitted from the boiler to the larger one. The duty of the pump is to force the water into the accumulator, with a pressure of twice that of the steam in the boiler, which is acting upon the larger piston. The pressure may of course be increased to any amount by adjusting the relative proportions of the two pistons in the accumulator and the two in the steam pump. The pressure is communicated to the continuous pipe C, and so to the cylinders and pistons D on the carriages, by which the brakes are applied.

453.





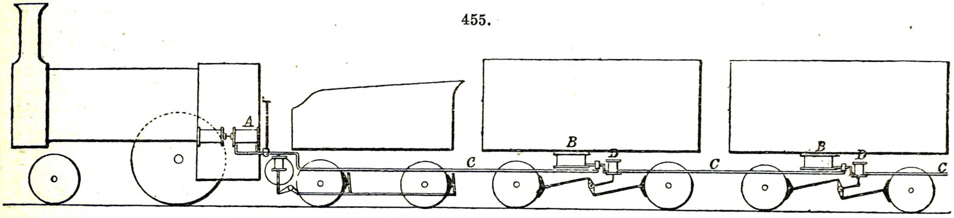
454.

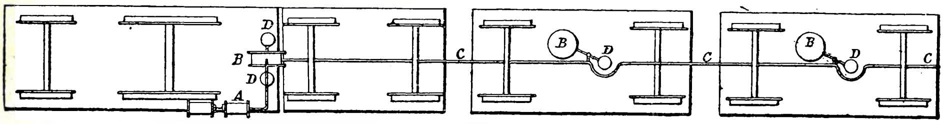
This hydraulic brake can be applied or released by the driver. To make the brake act automatically, powerful springs S have been introduced on each carriage, which are put into compression by means of separate cylinders and pistons E, connected with the accumulator B by a separate pipe F, so as to be always under pressure. These springs act as accumulators; and if by a separation of the train the pipe F is broken, they react upon the water in their cylinders E, so as to force it into the brake cylinders D and apply the brakes. Self-closing valves are of course required for the pipe C, as in the vacuum brake. There is no cord communication, and the brake is its own tell-tale. It is necessary to provide against the effect of frost; and this is done by using a solution of salt and water, or of water and glycerine, both of which mixtures freeze at very low temperatures. A small tank H containing the solution is placed on the tender, from which the steam pump takes suction. This tank supply provides for the loss arising from leakage, and from the disconnection of the couplings between the carriages, when the train is broken up.

In the application of compressed air a great many forms of brakes have been suggested, all of which consist essentially of an air-compressing pump, worked from one of the axles of the train, or by steam from the locomotive boiler, a reservoir, a continuous pipe, and cylinders and pistons on the carriages, by which pressure is brought upon the brake blocks, when the cylinders are put into communication with the reservoir through the continuous pipe. As none of these forms fulfil the necessary conditions, it is useless to enter into a detailed description.

In the automatic compressed-air brake, Figs. 455 to 458, a donkey pump A is kept continually at work by steam from the locomotive, in order to maintain a constant compressed-air pressure of 60 to 70 lb. on the sq. in. in the continuous pipe C and the reservoirs B, one of which is placed upon each carriage. In connection with the reservoir B is a cylinder and piston D, by which the brakes are applied. Between the reservoir and the cylinder is a regulator E, to regulate the flow of compressed air from the reservoir to the cylinder, when the brakes are applied, and to release the compressed air from the cylinder when the brakes are taken off, and, at the same time, to admit a further supply of compressed air to the reservoir for the purpose of recharging it.

455.



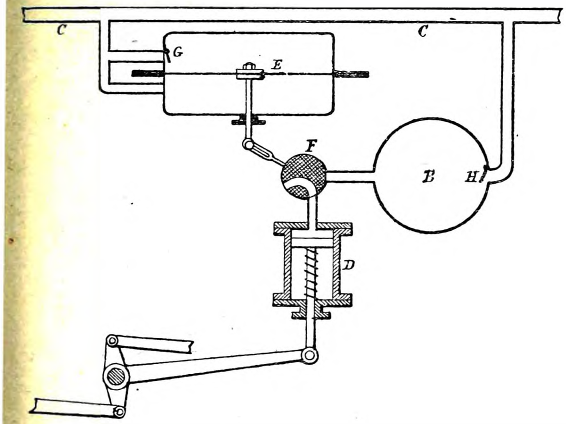


456.

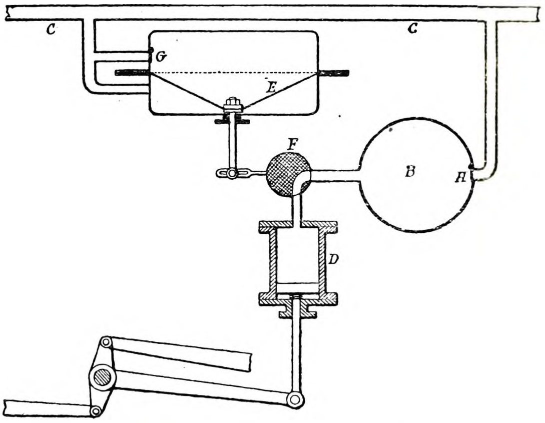
The pressure is admitted to act on both sides of the elastic diaphragm or piston E, and this operates upon an arrangement of valves, which, for the sake of simplicity, is represented by a cock F.

So long as the normal pressure in the continuous pipe C is maintained, equal pressures are also maintained on both sides of the diaphragm E, and it is therefore inoperative, as in Fig. 457; but when the pressure in the pipe C is reduced for the purpose of applying the brakes, a similar reduction of pressure takes place on the under side of the diaphragm, which is then forced downwards by the pressure of the air confined on the upper side, Fig. 458. This motion, operating upon the cock F, establishes a communication between the reservoir B and the cylinder D, and the brakes are applied. Upon restoration of the normal pressure the diaphragm is again put into equilibrium, and by its motion upwards, it operates upon the cock in such a manner as to shut off the connection between the reservoir and the cylinder, and to open a passage for the free exit of the compressed air in the cylinder, this air being then driven out into the atmosphere by the action of a spring beneath the piston, which is employed to take the brakes off. The valves, G and H, are for the purpose of retaining the pressure on the upper side of the diaphragm E, and in the reservoir B, at the time when the pressure in the continuous pipe is reduced, for the purpose of applying the brakes. In order to apply the brakes, it is only necessary to reduce the normal

457.



458.



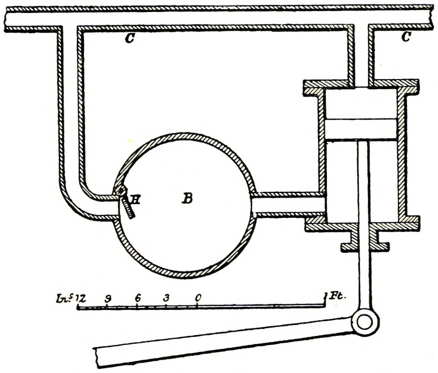
pressure in the continuous pipe, sufficiently for destroying the equilibrium of the diaphragm, and this can be done at any part of the train, by opening a cock, or by the accidental separation of the train or of the couplings between the carriages. This application of compressed air is therefore automatic, and it fulfils all necessary conditions.

The efficiency of this principle appears to depend upon the pump maintaining a constant pressure in the continuous pipe, and on both sides of the diaphragm; for should any reduction of pressure, however small, take place from the imperfect working of the pump, or from leakage in the pipe, the equilibrium of the diaphragm would be destroyed, and the brakes would be applied at a time when perhaps it was not intended; and after they were applied, unless the pump were capable of restoring the normal pressure, a difficulty might arise in taking them off, except by releasing the air by other means from the cylinder on each carriage. It also appears that by this arrangement there is no means of regulating the power of the brakes.

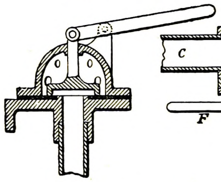
Compressed air has a tendency to escape in all directions and to blow the couplings apart; the perfect working of this principle appears therefore to depend upon the perfection of the workmanship.

Compressed air has also been applied automatically, by means of a reservoir and a cylinder and piston on each carriage, the pressure being maintained on both sides of the piston. This arrangement is shown in Fig. 459. As the area of the under side of the piston is diminished by the rod, there is an excess of total pressure on the top side, which keeps the piston at the bottom of the cylinder, so long as the pressure is maintained on both sides of it. In the air-reservoir B is a retaining valve H, which closes towards the continuous pipe C. The brake is applied by decreasing the pressure in the continuous pipe, leaving the piston free to be moved upwards, by the expansion of the compressed air underneath it, from the air-reservoir B. The power of the brake depends upon the quantity of compressed air allowed to escape from the continuous pipe, to reduce the pressure on the top side of the piston; and the power can therefore be regulated as required. This brake is its own tell-tale; and all the four conditions are fulfilled.

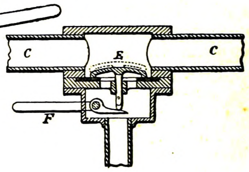
459.

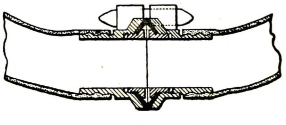


460.



461.



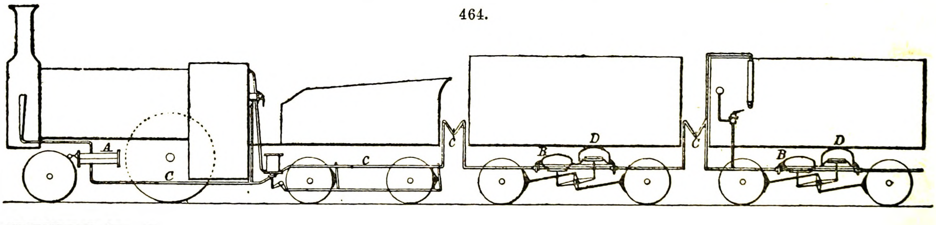


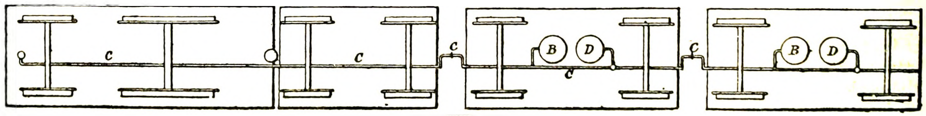
463.

462.

In the automatic vacuum brake, as designed by R. D. Sanders, Figs. 460 to 467, a vacuum is created in the continuous pipe C by means of an ejector on the engine, and is subsequently maintained by an exhausting pump A, worked from a reciprocating part of the engine. The function of this pump is not to create the necessary power, but to maintain it, by withdrawing the air which

464.



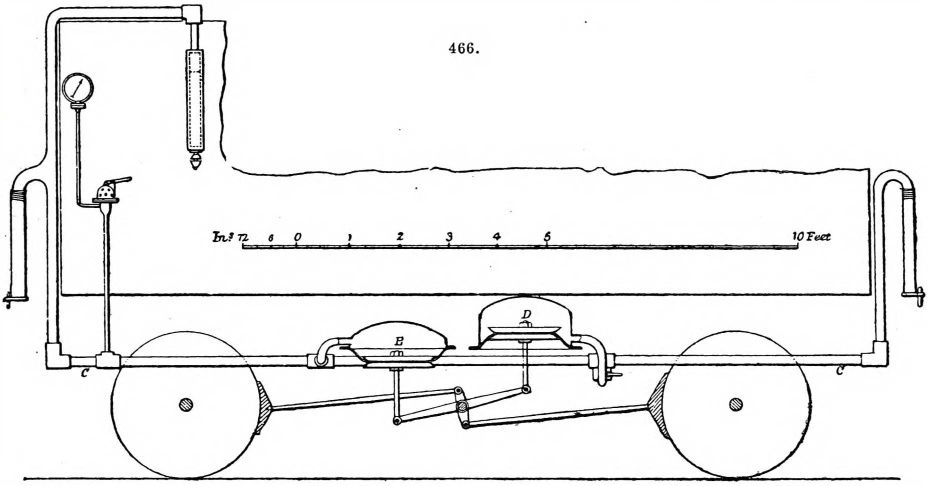


465.

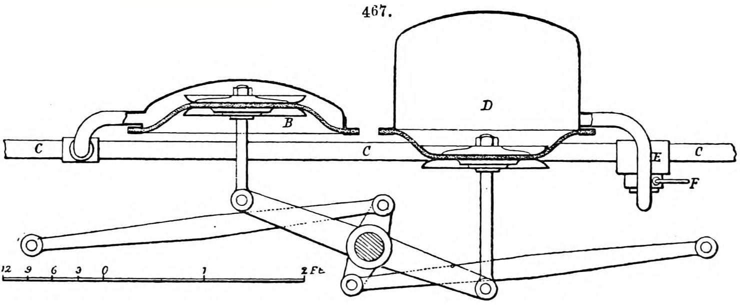
must, through leakage, find its way into the pipe. On each carriage are two drums B and D with flexible heads, of different areas, Figs. 466 and 467, which being connected with the continuous pipe and with the brake gearing, pull in opposite directions. The larger drum B is employed to keep the brakes out of action, and the smaller one D to apply them. In the connection between the smaller drum D and the continuous pipe C, is a self-closing valve E, Fig. 460, for maintaining the vacuum in the smaller drum when air is admitted into the continuous pipe.

When a vacuum is created in the continuous pipe, the air is simultaneously withdrawn from both drums, but the pressure of the atmosphere acting upon the head of the larger or pull-off drum, overbalances that upon the head of the smaller or pull-on drum. As they are connected to the opposite ends of the same lever, the arms of which are of equal length, the difference of power between the larger drum and the smaller, is constantly employed in keeping the brakes out of action. In order to apply the brakes, it is necessary to destroy the vacuum in the larger drum, which is done by admitting air into the continuous pipe, either by means of a hand valve on the engine, or in the guards' vans, Fig. 461, or by an accidental disconnection of the couplings between the carriages. The admission of air into the continuous pipe does not, however, destroy the vacuum in the smaller or pull-on drum, on account of its being sealed by the self-closing air-valve E. This valve can be opened by hand by an external lever F, Fig. 460, for admitting air into the pull-on drum if necessary, so as to release the brakes when shunting a carriage off. The coupling of the connecting pipe between the carriages is shown in Figs. 462 and 463.

466.



467.



The action of the two drums is as follows. The effective power of the larger or pull-off drum is 380 sq. in. × 10 lb. vacuum = 3800 lb., whilst that of the smaller or pull-on drum is 314 sq. in. × 10 lb. = 3140 lb. There is therefore with a 10 lb. vacuum an excess of power equal to 660 lb. in each pull-off drum, acting to keep the brakes out of action. When the normal vacuum in the continuous pipe is reduced say $17\frac{1}{2}$ per cent., the two drums are in equilibrium; but this diminution of pressure does not apply the brakes, because the larger drum is still pulling with equal power against the smaller. The brakes can only be put on by still further reducing the vacuum in the larger drum; and in proportion to such reduction the pull-on drum is permitted to apply them. Only the total destruction of the vacuum in the pull-off drum allows the other drum to apply the brake blocks with full effect.

By this arrangement of opposing powers, the efficiency of the brake does not depend upon the normal vacuum being kept up constantly to the full amount, but it may be reduced $17\frac{1}{2}$ per cent. without affecting the brakes; and the power of the brakes can be regulated, by the quantity of air admitted into the continuous pipe in any part of its length. The brake is its own tell-tale, and its power is always registered in front of the driver by means of a vacuum gauge. As the external pressure of the atmosphere always presses upon the outside of the pipes and apparatus, there is no danger of the couplings being blown apart. On the contrary, they are firmly held together by the external pressure upon them; and for this reason there is in this system a tendency to reduce rather than aggravate imperfections of workmanship.

In the discussion upon Sanders' paper, A. Barclay pointed out that the maximum power which could be applied to any brake could not do more than skid the wheels; so that, whatever pressure in the apparatus, as soon as that result was obtained and the wheels stopped revolving, the brake had done all it could. In the vacuum brake, however far the vacuum was from being complete, it was only necessary so to increase the area of the vacuum chamber as to get the desired effect. Sanders' brake was automatic in this sense, that if the connection between the carriages were broken, the brake would be put on. Screw brakes were originally applied on lines having very steep inclines. Afterwards, in the case of the Metropolitan lines, it was found that the traffic could not pass over the lines fast enough, unless some continuous brake was employed for enabling the trains to pull up quickly at the stations. When the brake was so employed and the traffic thus got over the line faster, the idea was started of applying the same brake on fast through trains, to prevent collisions.

J. Tomlinson remarked that the Metropolitan Railway had adopted the continuous brake from a commercial point of view. They had previously used hand brakes at both ends of the train, and the result had been that the wheels had to be taken out of the carriages about every eight or ten weeks to be turned up. The vacuum brake was introduced by putting a brake upon four wheels of every coach, or half the wheels, and the result had been that the amount cut off in the turnings of carriage wheels was exactly half what it had been previously, for the same number of train miles. Therefore he had no hesitation in saying that the continuous brake properly applied on a railway effected a very great saving commercially, and that in other directions besides the turning of the wheels.

W. B. Wright said the automatic principle was very valuable, inasmuch as sometimes from negligence on the part of a porter a coupling might not be securely coupled up, and a driver relying on the brake might, perhaps, run into a terminus against the buffers at the end, or might overshoot a through station. He had known two cases of that kind with a continuous brake in which the automatic principle was not in use. In one case there was a defect in the coupling between the tender and the next vehicle, and in the other by the negligence of a porter the coupling had come undone. Both cases resulted in overshooting the station.

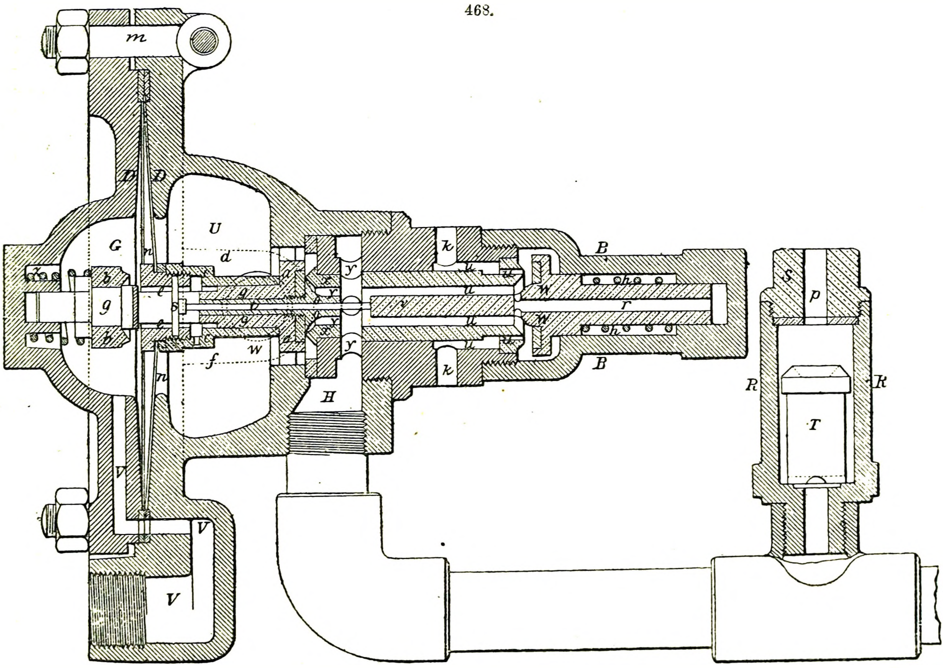
C. Hawksley, referring to what had been stated about there being no possibility of doing anything beyond merely skidding the wheels, said it had been pointed out to him some years ago by W. Bouch of Shildon, that brakes were the most effective when the wheels were not completely skidded, but allowed to revolve at a very slow rate. That had reference more especially to working on an incline, where for 5 miles of line there was a gradient of about 1 in 50. Bouch had explained it in this way, that, when the wheels were completely skidded, they became very much heated at one point, and rubbed flat and bright, and then there was not so much adhesion to the rail as when they were allowed to revolve very slowly. This could not, of course, apply to cases where the train had been pulled up very rapidly, and where there might not be time for the same heating action to take place as when running down a long incline, as when a heavy mineral train was running down the incline mentioned of 5 miles in length.

G. Westinghouse, jun., said he had found in various experiments that every time the leverage or the pressure was increased, and a greater force brought against the wheels, better results were obtained. In some cases an air pressure of 100 or 101 lb. on the sq. in. had been used. On the North British Railway 101 lb. pressure was sufficient to cause the piston to move through the whole distance of 12 in., and to bring a maximum pressure on the brake piston itself of about 80 lb. on the sq. in., or 4000 lb. total pressure moving through a distance of 1 ft. In that case there was one block only against each wheel; but experience had shown that, to do the very best braking, double blocks on each wheel were required, and that a force should be brought against the wheels equal to at least 2½ times the weight of the wheel on the rail. In many of the competitive experiments it had been 1¼ and 1½ times. But the most important point was the storing of the power under the carriage. The Westinghouse automatic system had been first introduced upon 150 railways, but the railway authorities complained of the difficulty arising from couplings coming apart, and from the train sometimes overrunning the station through inability to apply the brake, and that, as the brake was not a tell-tale, it was liable to produce accidents or become useless. Attention was then given to the storing of power under each carriage. One plan was similar to Fig. 459, known as Steele's brake. Experiments, with apparatus substantially the same as the Steele brake, had shown considerable difficulty in applying the brake. For storing power in that case, there was about 800 cub. in. of space a carriage, filled with air at about 60 lb. or 80 lb. pressure on the sq. in., or say 4000 cub. in. of air at atmospheric pressure a carriage. This pressure had to be entirely taken off before the brakes were fully applied, and the 4000 cub. in. of air a carriage, with a train of ten carriages, passing through a small pipe, took a considerable time to escape. It was necessary to bring the power of the reservoir into action by means of a very small movement of air; and this resulted in the use of what was called the triple valve. This valve had three motions. It governed the flow of air from the brake pipe to a small reservoir under each carriage, from this reservoir to the brake cylinder, and from the brake cylinder to the atmosphere. In charging the reservoirs under the carriages, the air was conveyed through the brake pipe, and stored at a pressure amounting in express trains to from 80 to 90 lb., and sometimes more. The brake was applied by making a slight reduction of pressure in the pipe alone, say 15 lb. reduction. The triple valves were then opened, so as to make communications from the reservoirs to the brake cylinders; and the air in the reservoirs acting on the pistons, applied the brakes. Thirty cub. in. of compressed air removed from the brake pipe for each carriage was enough to cause the brakes to be fully applied, or say 300 cub. in. on a train of ten carriages. Smith's vacuum brake was operated by withdrawing the air; and about the same quantity of air had to be removed in order to apply that brake, as was allowed to flow-in in order to apply Sanders' brake. What had been gained therefore in the Westinghouse automatic brake, was altogether owing to its quickness of application. The brake could be brought into full play within 1½ second. With regard to the automatic action, the action of the brake could be easily graduated. The pressure in the pipe of 70 lb. on the sq. in. was not all applied to the brakes. If that pressure were reduced by 15 lb., the brake was put full on; if it were reduced by 3 or 4 lb. only, it let an equivalent proportion of air from the reservoir into the cylinder.

The Committee of the Franklin Institute, to whom was referred for examination the Westinghouse air-brake, have made a report upon this system. In its original and simplest form this brake consisted of a small steam engine placed on the locomotive, which, taking steam from the boiler, operated an air-pump, which compressed air into a main reservoir. By a line of pipe beneath the carriages, the compressed air was admitted at the pleasure of the engineer, who controlled its flow, by a three-way cock, to a series of brake cylinders, one under each carriage, the pistons of which acted upon the ordinary brake levers, and applied the brakes to the wheels. By reversing the three-way cock, the air was allowed to escape from the cylinders, and the brakes were off. As it required an appreciable length of time, especially in long trains, for the air, even under considerable pressure, to travel from the main reservoir to the brake cylinders, Westinghouse devised means by which the compressed air can be admitted almost instantaneously into the brake cylinders. The brakes can be applied from any part of the train. The brakes will be at once applied automatically in each car, should an axle break, or a carriage or the engine leave the track, or should the train be broken. An auxiliary reservoir for compressed air is placed on each car, close to the air-cylinder. These auxiliary reservoirs are connected with the main reservoir by a pipe, without coupling valves, so that the same fluid pressure will be preserved in them as in the main reservoir. But the compressed air, before entering the auxiliary reservoirs, passes in each case through a valve-box containing a triple valve, and from which valve-box, one port leads to the auxiliary reservoir, one to the brake cylinder, and a third to the open air. This triple valve is of such construction with reference to the ports that, so long as the air pressure is kept up in the air-pipe, the auxiliary reservoirs will be kept charged at the same pressure, and at the same time the ports intermediate between the brake cylinder and the external air, will be open; then, of course, the brakes will be off, and the train will be in running order. But on the pressure in the air-pipe being reduced, the ports between the air-charging pipe and each auxiliary reservoir will be automatically closed, as also the ports between the brake cylinders and the external air; and at the same time, the ports will be opened between each auxiliary reservoir and its corresponding brake cylinder. By restoring the air pressure in the charging pipe, and connection with the main reservoir, the position of the triple valve is shifted, so as to close communication between the auxiliary reservoirs and brake cylinders, and open communication from the latter to the external atmosphere. This operation is as quick in action as the other, and the brakes being released the train is again in running order.

The valve-box or case B, Fig. 468, is made in two or more parts. The air-charging pipe from the main reservoir is attached to the port V, which leads into the air-chamber G. From the opposite chamber U, the port W leads by a suitable pipe connection to the auxiliary reservoir and a like pipe leads from the port H to the brake cylinder. The valve stem *g* has a limited motion longitudinally in the chambers G U. At one end it carries the valve *a*, which seats on the annular V-shaped seat *x* by packing on its lower face, so as when seated, to close the port *y*. A series of wings arranged on this end of the stem *g*, act as guides in properly seating the valve *a*. A spring *z*, arranged on the other end of the stem *g*, bearing against the cap of the valve case and against the back face of the valve seat *b*, holds the valve *a* to its seat when not raised by air pressure. The air-chambers G U are separated by a flexible diaphragm *n*, of sheet metal, the outer edge of which is compressed between the adjacent faces of the two parts of the valve-box,

468.



with elastic packing rings of indiarubber. From these annular packing surfaces, the parts of the case are so shaped inwardly as to give two annular flanges D, the distance between which gradually increases towards their inner edges, but the slope of each is such, that so much of the diaphragm *n* as comes between them, shall rest on one or the other at the end of each stroke of the stem *g*. The sloping surfaces of these flanges D constitute seats or rests to support the diaphragm after it has done its work, and prevent its breaking.

The diaphragm *n* has an eye at the centre through which passes the stem *g*, and the annular edge of this eye is clamped between two rings, which form parts of the compound piston *c*. The compound piston *c* is free to move on the stem *g* longitudinally, and its face is provided with packing, so as to make a tight joint when seated against the annular ring of the valve seat *b*. Commencing at a point a short distance from the upper valve seat *b*, the stem *g* is turned smaller, and is also slotted. This reduction in the size of the stem *g* gives an annular air-port *e*, by which communication is secured between the two chambers, G U. The compound piston *c*, has an extension *d*, around the stem *g*, by means of which, in moving each way on the stem *g*, it alternately covers and uncovers the port *e*, and thereby closes and opens communication between the two chambers G U. The annular port *e* communicates with the valve chamber U by means of ports *f*. Across the slot in the stem *g*, a cross-bar *s* is arranged, with its ends fixed in position in the adjacent walls of the nut *c*. From this slotted part a pin *t* extends through the stem *g*, till it butts against the stem *v* of the third valve.

The extension of the valve-box or case contains this valve *w*, which seats against a valve-seat, so as to close an annular port *u*. By this port and the passages *u*, communication is effected through the valve *w* being unseated, between the brake cylinder by the port H, and the external atmosphere by the ports *k*, for the purpose of allowing the compressed air to escape from the brake cylinder when the brakes are to be released. The valve *w* is seated and unseated by the action of the spring *h*, and the pin *t* acting on the stem *v*, as presently to be explained. To provide for an equilibrium of air pressure on both sides of the valve *w*, holes *r* are bored through it and its stem. The operation is as follows;—If air under pressure is admitted by the port V, it will by the pressure it exerts on the flexible diaphragm *n*, cause the piston *c* to be shifted on the stem *g*, until it occupies about the position shown. The cross-bar *s* will then have opened the valve *w*, and the valve *a* will be closed by means of the spring *z*; also the annular port *e* will be opened. In such case, the air will pass from the chamber G, along the ports *e f* into the chamber U, and out of the port W to the auxiliary reservoir. The auxiliary reservoir will then be charged with compressed air, of such density as it may be desired to store up for the purpose of operating the brakes. At the same time, the valve *w* is unseated, and a direct communication opened from the brake cylinder, through the port H, and the ports *k*, with the external atmosphere. The brakes are then off. As soon as the pressure on the opposite side of the diaphragm *n*, is equal or nearly so, the spring *h* in the lower part of the case, acting against the valve *w* and through the stem *v*, pin *t*, and cross-bar *s*, will cause the piston *c* to slide upward on the stem *g*, and cut off communication through the annular passage *e*, and will seat the valve *w* so as to cut off the escape of air from the brake cylinder through the escape ports *k*. Then, if the pressure exerted in the chamber G on the diaphragm *n* be reduced, by allowing a portion of the air to escape from the charging pipe, the pressure acting back through the port W on the opposite side of the diaphragm *n*, will raise the piston *c* against the valve seat *b*, compress the spring *z*, and by moving the stem *g* in the same direction, will lift the valve *a* from its seat *x*, and open communication from the chamber U, through the port *y*, with the port H. The compressed air will then be free to pass from the auxiliary reservoir, through the ports W, *y*, and H, to the brake cylinder, so as to apply the brakes. The area of the opening through the port *y*, is regulated by the distance which the plug *o* is caused to move outwardly from the port. Hence, if the pressure be reduced but slightly at V, the plug *o* will be raised but a short distance, and a small amount of air will be allowed to pass through and out at the port H. When the equilibrium is restored in the chambers G U, the valve *a* will resume its seat and close communication. If the pressure in the chamber G be materially increased, the valve *w* will be unseated, as already described, and an open communication be made from the brake cylinder through the port H and *k*, to the external atmosphere. By the use of the taper plug *o*, and by regulating, as can easily be done by cocks, the amount of pressure in the chambers G U, it is easy to regulate the amount or density of the air which is permitted to flow through the ports *y* into the brake cylinder, and consequently easy to regulate and adjust, at all times, the force with which the brakes are applied. This force may be varied from the maximum power of the brakes, down to the fractional part of a pound in excess of ordinary atmospheric pressure.

When a car is detached from a train, the charging pipe should be closed at each end before the car is detached, to prevent the brakes being applied by the reduction of the pressure. In this case, if, as will sometimes happen, the air leaks slightly from the charging pipe, the valve *a* will be raised slightly from its seat, and the air will pass slowly from the reservoir by the port W, through the port *y*, and by the port H to the brake cylinder, and set the brakes. To prevent this, a relief valve is arranged on the pipe from H. This valve consists of a cylindrical box R, having a cap S with a small port *p* bored, and faced with rubber packing *p*. In the chamber of the case R is a valve T working loosely, and having on its upper end a seat of suitable form, so that when forced up by the ordinary pressure in working the brakes, it will seat against the packing and effectually close the port *p*. But when the pressure is only such as may result from leakage, such pressure will pass out through the lower port, and tilting the valve T off its lower seat, will pass by it without seating it upward. The amount of pressure which may in this manner be allowed to escape without the application of the brakes, may be varied at pleasure by varying the size and weight of the valve T.

For greater convenience and facility in opening and closing the valve case B, a fastening has been devised. One part of the case fits on to the other part like a cap, and is held in place by eye-bolts *m*, which fit into a recess, or between lugs. These eye-bolts are held in place at one end by pins, which pass through the eye ends of the bolts and through lugs on the one part of the case. These bolts are threaded at the opposite ends, and secured so as to hold the two parts of the valve case together by screw-nuts. The threaded ends of the bolts project a short distance beyond the outer faces of the nuts, when the latter are screwed down tight, and such projecting ends are riveted or upset slightly, so that while leaving room for the nuts to be unscrewed, sufficiently for the bolts *m* to swing outwardly from the recesses in the cap B, turning for that purpose like hinges on the pins, they cannot be screwed off entirely so as to be lost, but will always be in place for use.

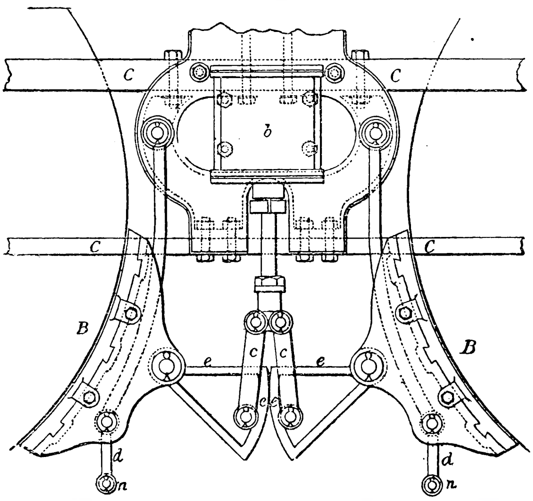
Each auxiliary reservoir has about four times the capacity of the corresponding brake cylinder. The charging pipe, which is of three-quarter inch gas pipe, extends from the main reservoir under the whole train, and is provided with a three-way cock on the engine, by which the entire apparatus for ordinary braking purposes is placed under the control of the engineer. This pipe is, between the cars, provided with flexible sections, on the outer side of which are couplings, counterparts of each other. These couplings have no valves for retaining the compressed air when uncoupled, but a cock is inserted in the pipe, at the ends of each car, for closing the pipe at the rear end of the train, and also at each end of a car, when such car is detached from a train.

The advantage of an instantaneous application of the brakes at the will of the engineer is obvious. In the system before in use, the pressure has to be transmitted back through the train. In the improvement described, the requisite pressure is kept up throughout the train, ready to be put into operation. In the former case, 1200 cub. in. of compressed air at 35 lb. pressure on the square inch for each car, or 2800 cub. in. at atmospheric pressure, have to be transmitted back from car to car to apply the brakes effectually. In the latter case, a reduction of 15 lb. in the pressure of the air in the pipe, equivalent to the pressure of one atmosphere, is all that is necessary to effect the same result. This reduction of pressure is equivalent to the transmittal of 360 cub. in. of air for each car at atmospheric pressure. The saving of time in applying the brakes will then be, approximately, in the proportion of the quantity of air transmitted, or as 2800 is to 360.

This relative proportion is affected only by the friction of the air in passing through the pipes, and this element is comparatively inappreciable as affecting the result. By arranging the auxiliary reservoir and the brake cylinder of each car in close proximity with each other, the time required for the air to pass will be so small as to be unimportant. From the construction of the apparatus, its durability is limited only by the number of times that the valves will bear the operation in the application and release of the brakes. All the material being of metal, will not be appreciably affected by age.

To test the number of operations that would be required to destroy the apparatus or any breakable part, this triple-valve device was arranged in connection with a charging pipe and brake cylinders, as in a train, while a three-way cock on the pipe was operated by machinery, as in ordinary use for braking purposes. After the reservoirs were charged with compressed air at ordinary working pressure, the machinery which opened and closed the three-way cock was set in motion, and the triple-valve began its work. After 309,000 strokes in opening and closing the ports, which was equivalent to applying and releasing the brakes that number of times, it was still found in perfect working order, so far as could be ascertained from its operation. Upon examination it was found that the diaphragm *n*, showed signs of cracking at a point between the rubber packing rings. The other parts of the triple-valve made 460,000 strokes without any indication of failure. These experiments have been continued at great length, and in no case has the triple-valve failed to perform its work promptly and effectively. In these tests, the piston of the brake cylinder received a full and complete stroke, so that the shock, and, of course, the strain on the triple-valve, is more severe than in ordinary train use.

469.

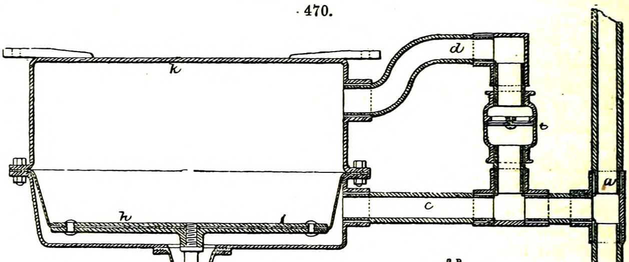


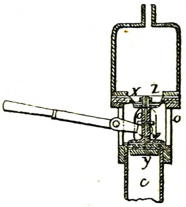
An improvement in the Westinghouse system is for the driving wheels of locomotives, Fig. 469. B are the ordinary driving wheels, and C indicates portions of the framework of the locomotive. The brakes proper *d*, are recessed on their rear faces and are pivoted to the hangers, below and a little forward of their centres of gravity, so as naturally and by their own weight to swing clear of the wheels. To these brake-shoes are pivoted the eccentric-faced segment levers *e*, in such position that their curved faces work against each other, or against a block placed between them. At any desired points in the direction of the length of their curved faces, preferably near the lower ends, the connecting rods *c* are pivoted, which at their upper ends are jointed to the lower end of the piston stem. The segment levers *e* are somewhat eccentric, their working faces at the lower ends being somewhat further from their centres of motion than at their upper ends.

This apparatus, together with the brake cylinder *b*, is duplicated on the opposite side of the locomotive. The compressed air is admitted by a pipe from the main reservoir, with an interposed three-way cock beneath the piston in the brake cylinders *b*, and by the upward thrust imparted to the piston-stem *c*, shifts the segment levers *e*, so as, acting on the principle of the toggle joint, to apply the brakes effectually to the wheels. By this construction, in fact, the ordinary advantages of the toggle joint are secured along with a nearly uniform application of the power at all points of the stroke, until the brake-shoes are worn entirely away. Where the distance between the drivers B is too small to admit of the introduction and use of both the segment levers *e*, one only can be used, pivoted to one of the brake blocks, and with its eccentric face working against a friction roller pivoted to the other brake block.

Figs. 470 and 471 are of Aspinall's automatic vacuum brake. Fig. 470 is of the arrangement when only a single pipe running throughout the train is employed. Under each carriage in the train is placed a cylinder, having both ends closed to the atmosphere. In each cylinder, a piston *h*, Fig. 470, is attached by a flexible diaphragm to the sides of the cylinder *k*. To this piston is connected a rod *l*, working in a collapsible leather tube *m*, fixed to the lower end of the cylinder *k*. This rod communicates with the brake levers. The top and larger compartment of the cylinder *k*, above the piston *h*, communicates with the pipe *a* running throughout the train, by a branch pipe *d*, in which is a valve *t*. This valve allows air to be drawn out of, but not returned to, the upper compartment of the cylinder *k*; another branch pipe *c* communicates with the bottom of the cylinder and the train-pipe *a*. A vacuum of about 20 in. is, by means of a small ejector, maintained throughout the train-pipe, and above and below the pistons under each vehicle. To apply the brakes, either the driver or guard can admit air to the train-pipe, when it immediately flows below all the pistons, but cannot flow above them, as it closes the valve *t* in the branch pipe *d*. The piston is forced up by atmospheric pressure, and the brakes are applied. In order to take off the brake, the driver recreates a vacuum in the train-pipe, and consequently in the lower part of the cylinder; the piston falls by gravity, and releases the brake. A vacuum gauge upon the engine, and in each of the guard's vans, shows at all times what brake power is at the command of those in charge of the train. In each of the guard's vans is a valve, Fig. 471, by which air can be admitted to the train-pipe. This valve is constructed so that it opens automatically whenever the brake is applied from any cause, and thus secures the admission of air to several parts of the train-pipe simultaneously. This valve is formed with two heads *w* and *x*, connected by a spindle. The lower head, which is the larger in diameter, seats on the top of the train-pipe. The smaller head is attached by a leather diaphragm to the bottom of a chamber *z*, which communicates with the pipe *c*, by means of a very small hole *y* through the spindle. The atmosphere is free to enter above the head *w*, and below the head *x*, by the large openings *o o*. A lever is attached to the spindle so that the valve may be moved by hand. So long as the vacuum is maintained in the pipe *c*, and through the hole *y*, in the chamber *z*, the valve *w*, by reason of its possessing the larger head, is held firmly in its seat, but when the vacuum is partially destroyed in the train-pipe *c*, the atmosphere forces up the part *x* and lifts the head *w* off its seat, thus admitting air into *c* and applying the brakes. The air then gradually flows through the small hole *y* into the chamber *z*, and the valve once more descends to its seat. Means are provided for opening the valves leading to the tops of the cylinders, so that the brakes may be taken off at terminal stations. A valve on the engine enables the driver to admit air to the train-pipe, at the same time that he shuts off the ejector from exhausting.

470.





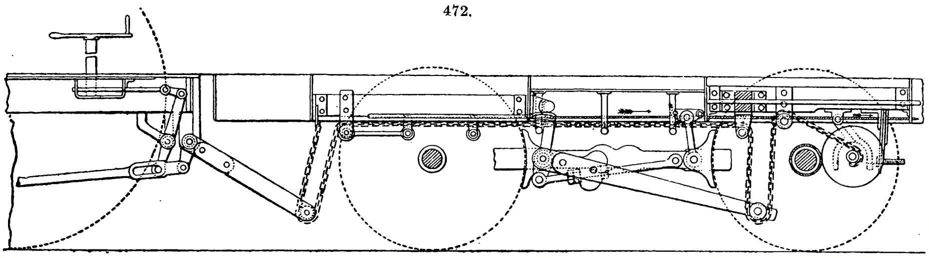
471.

An electric brake, invented by Achard, has been under public notice in France for many years, it is only now developed into anything like a practical form, and has met with some approval at the hands of French railway companies.

Fig. 472 represents the brake as applied to a locomotive and a tender. Normally, the cylindrical electro-magnet ought to be concentric with the axle and move with it. The armature forms the sides of a sleeve also mounted on the axle, but loose, so that it does not revolve with the wheels. A chain forming the transmission to the brake is rolled on the surface of the sleeve, and produces a braking effect, proportional to the advance of the train. This arrangement, as first introduced, required modification on account of the speed given to the parts mounted direct on the axle. The principle has been preserved by employing a shaft parallel to the axle, geared by the friction of a disc kept in place by a spring. The velocity is thus reduced, and the duration of the various parts increased. In the brake represented the following parts are combined, the axle driving by friction the disc mounted on the adjacent shaft; a spring keeping the disc in contact with the axle; an electro-magnet mounted on the shaft parallel to the axle, and caused to revolve; two sleeves loose on the shaft parallel to the axle; these sleeves are terminated by two discs in soft iron, forming armatures, and of a diameter equal to that of the electro-magnet; the chain which actuates the brake, by rolling around the sleeves when these latter become connected to the action of the current. This chain passes over a pulley attached to the frame, and thence over another pulley at the end of a lever attached to the brake.

Two insulated electric cables are placed beneath the carriages, running right and left along the train, with connecting links between the carriages. Under each vehicle two secondary wires branch from the principal cables, one to the right and the other to the left. Thus two branches, suitably insulated, conduct the current from the circular electro-magnet, the principal part of the system. In the front and rear van is placed an accumulating Plante's battery, composed of four secondary elements of 4 in. diameter. These batteries remain constantly charged, and are sufficiently powerful to promptly stop a train composed of fourteen vehicles, including the engine and tender. In the front van above the battery is placed a commutator. A horizontal frame sliding in the roof of the vehicle allows the guard, by a lateral movement, to throw the springs of the commutator into metallic connection, and this is the only movement required to put on or off the brakes. The brake can be put in operation by the driver, a cord being attached to each end of the frame and led to the footplate, so that by pulling one or other of these cords the brake is thrown on or off; the train is, therefore, under the control of the driver, and of the front and rear guards.

472.



After a variety of experiments with different electro-magnets, Achard found that form designed by Nicklès to be the best. In this magnet there are two tubes of soft iron, one placed concentrically within the other, the interval being filled with wires covered with silk, and through which the current passes. If an iron armature is applied to connect the two cylindrical tubes, a second pole is found on the outer periphery, and the field of magnetic attraction is largely increased. The employment of tubes insures a maximum of power, with a minimum of mass. Achard's magnets support about 1760 lb., with the current from a Leclanché battery of three or four elements.

General Principles.—Captain Douglas Galton has found from an extended series of dynamometrical measurements, that the application of brakes to the wheels, when skidding is not produced, does not appear to retard the rapidity of rotation of the wheels. When the rotation of the wheels falls below that due to the speed at which the train is moving, skidding appears to follow immediately. The resistance which results from the application of brakes without skidding, is greater than that caused by skidded wheels. Just at the moment of skidding, the retarding force increases to an amount much beyond that which prevailed before the skidding took place; but immediately after the complete skidding has taken place, the retarding force falls again to much below what it was before the skidding. The pressure required to skid the wheels is much higher than that required to hold them skidded; and appears to bear a relation to the weight on the wheels themselves, as well as to their adhesion and velocity.

It would seem that the great increase in the frictional resistance of the blocks on the wheels, just before and at the moment of skidding, due to increase in the frictional resistance of the blocks on the wheels, this increase being itself due to the increase in the co-efficient of friction, when the relative motion of the blocks and the wheels becomes small, is what destroys the rotating momentum of the wheels so quickly. With constant pressures, the friction between the blocks and the wheels, and consequently the retarding force, increases as the velocity decreases. In order to obtain the maximum retarding power on the train, the wheels ought never to skid; but the pressure of the brake blocks on the wheels ought just to stop short of the skidding point. In order that this may be the case, the pressure between the blocks and the wheels ought to be very great when the brakes are first applied, and ought gradually to diminish until the train comes to rest.

BRICK-MAKING MACHINES.

The improvements devised in the construction of brick-making machines are very numerous. The various forms of construction of these machines may be included in the following classification, to which each machine is easily referable.

In one description of machine the clay is fed into a pug-mill, placed horizontally, which works and mixes it. It is then forced through a die of about 60 square in., of a form similar to a brick on edge. The corners of the die have to be rounded, as clay will pass smoothly only through rounded apertures. The clay, as it progresses from the mill, is seized by two vertical and two horizontal rollers, which roll it into a squared block of the exact size of the brick, with sharp edges, the rollers performing the function of a shifting die. The slab of clay thus formed is cut up into bricks by transversely-drawn knives or wires. A somewhat similar machine is described in this Dictionary, pages 650, 651.

In another description of machine, the clay passes from the pug-mill into moulds, where it is pressed, and whence the pressed brick is expelled. There are several varieties of this description; thus, the moulds are sometimes placed upon the upper surface of a mould-wheel revolving horizontally, and conveying the moulds successively beneath a pug-mill, from which they are charged. In other machines the moulds are placed on the periphery of a wheel, the clay, when in the mould, being pressed by exterior or interior pistons, and the pressed bricks discharged by piston-followers or the piston itself, actuated generally by cams or toggles.

In double-cylinder brick machines, two wheels are provided with peripheral moulds, charged with clay from a hopper above.

In continuous or belt machines, a series of moulds are linked together and passed beneath the charging-mill, whence they pass beneath a pressure-piston.

Besides the foregoing varieties of construction, the clay in some machines is moulded by reciprocating pistons, or a reciprocating action is imparted to the moulds beneath the pug-mill.

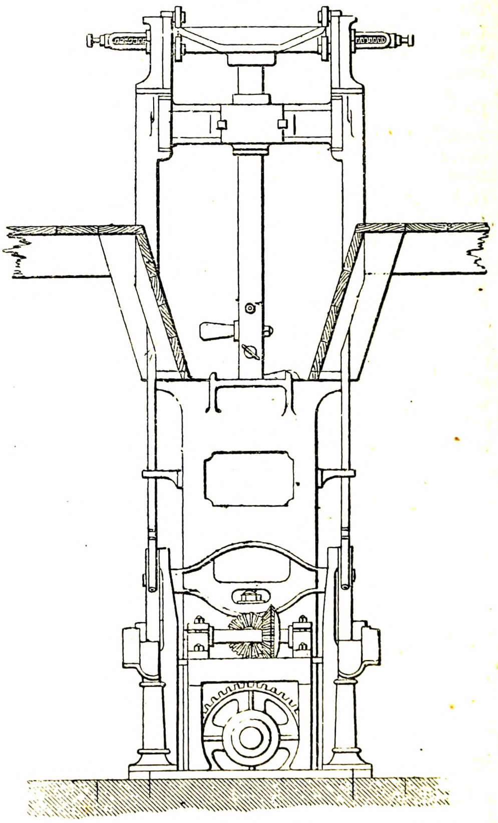
In another class of machines, the clay in a nearly dry state is compressed by a plunger into a mould, and expelled after sufficient pressure has been exerted to cause adhesion between the particles.

Bricks are also made of powdered dry clay, with sand and loam, moulded under hydraulic pressure.

The following machines described are typical of these classes, those types having been selected that have been introduced since the publication of the Dictionary, or omitted from its pages; and the types omitted in this Supplement will be found under the head of Brick Machines, at page 642 of the Dictionary.

Liddell's double brick-making machine, Figs. 473, 474, deals with the first part of the manufacture of bricks. It is driven from the main shaft, upon which is a bevel pinion gearing with a bevel wheel, fixed to the lower end of the vertical shaft. The lower end of the vertical shaft is supported in a step or socket, whilst the upper end is carried in bearings formed in the beam, which beam also serves to bind together the side frames standing upon the upper part of the pug-mill. Any required number of the ordinary pug-mill screw-blades are fixed upon the shaft, so that when the shaft is caused to revolve in the pug-mill the screw-blades mix or stir, and at the same time force the clay out of the pug-mill into the brick moulds formed in the slides. The pressing blocks, situated on each side of the machine, are actuated from a cam at the upper end of the shaft. Guides are carried on the frames, and in the guides slide-beds are formed, slides being placed therein. Upon the slides anti-friction rollers are acted upon by the cam, which, when revolving, causes the slides to rise and fall in the guides, and the pressing blocks being connected to the slides by the rods, they are raised and lowered. When the clay has been forced by the pressing blocks into the moulds in the slides, the slides are moved so as to bring another mould below the pressing blocks. These blocks are again lowered upon the clay, at the same time the brick last made is being forced out of the mould by one of the pressers, actuated from a cam fixed upon the shaft. Weights are attached to the pressers, and to the weights rods are fixed, their lower end sliding vertically in guides at right angles to the rods, the inner ends of the rods being provided with anti-friction rollers which bear upon the cam, so that by adjusting the cam on the shaft the pressers may be made to fall at the proper intervals for removing the bricks from the moulds.

473.

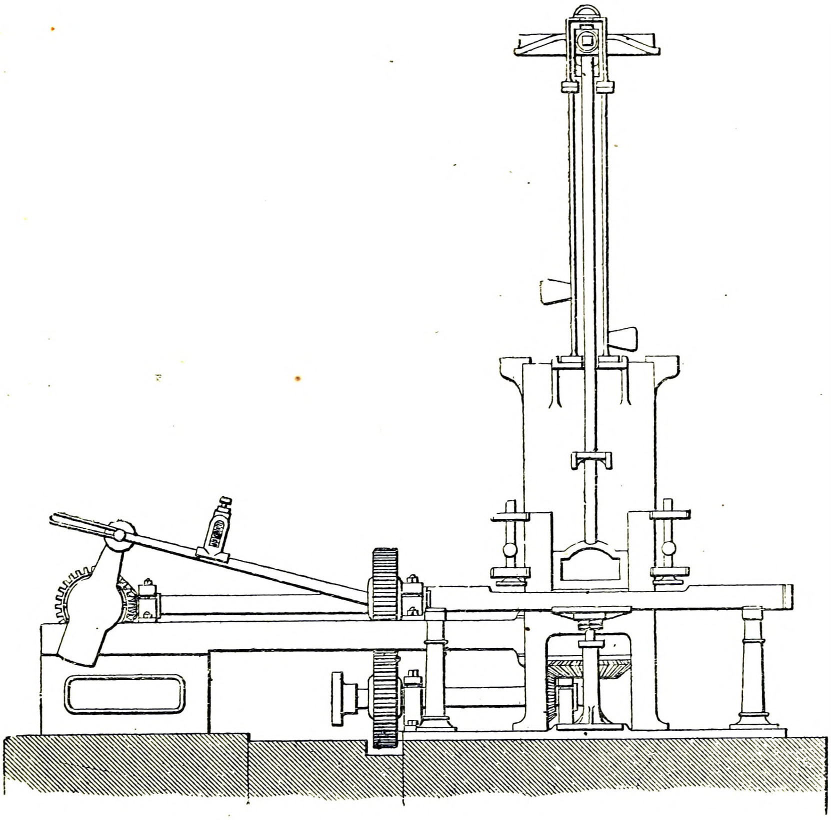


Amongst the advantages claimed for this machine is that it has only four bevel wheels, while other machines of a similar construction have no less than ten bevel wheels. The connecting rods from cranks to slides are so fitted with safety springs, that should a stone or piece of iron get in to the slides, the springs allow the connecting rods to pass, and thus prevent injury. The machine will turn out from 27,000 to 30,000 bricks a day. The engine required to drive it is one of 14-in. cylinder with a 30-in. stroke.

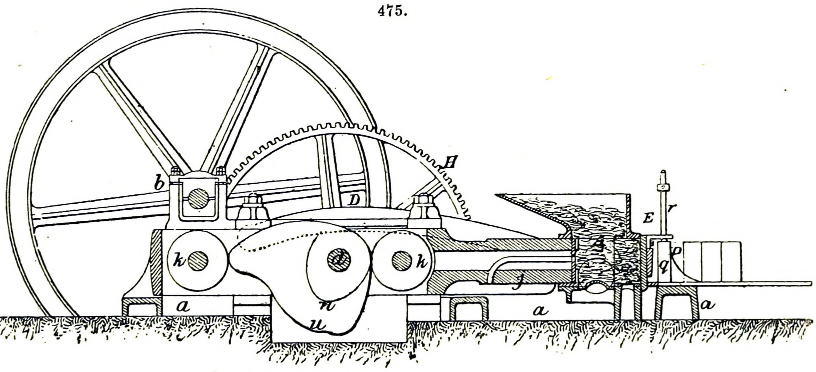
The most systematic way of working with this or similar machines is to have the clay conveyed in bogies drawn by chain or wire rope on a railway to the top of the pug-mill, where the clay is mixed with water into a plastic state.

Fig. 475 is a longitudinal elevation, partly in section, of Durand and Marais' machine; Fig. 476, a plan of the end from which the bricks are delivered; and Fig. 477, a vertical section of a modified construction of the mould with movable bottom. The machine is mounted on a cast-iron framing *a*. The framing has four plummer blocks *b b c c*, carrying two parallel transverse shafts *d f*, of which the one *f* carries the fast and loose driving pulleys *g*, a fly-wheel, and a pinion *h*, which is in gear

474.



475.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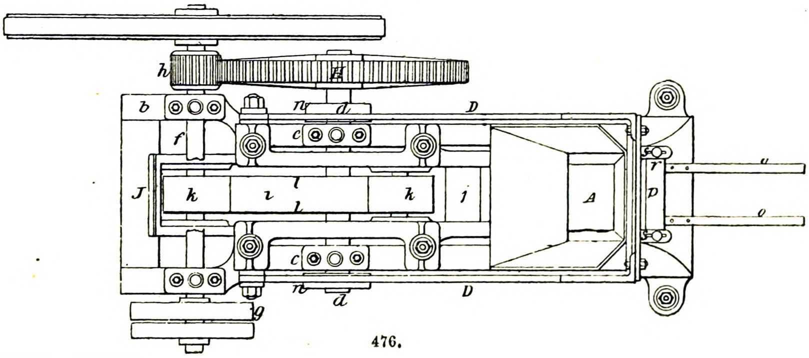
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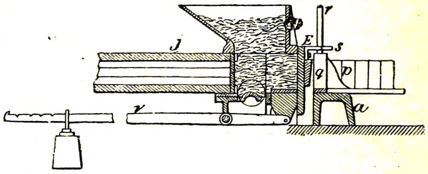
g

476.

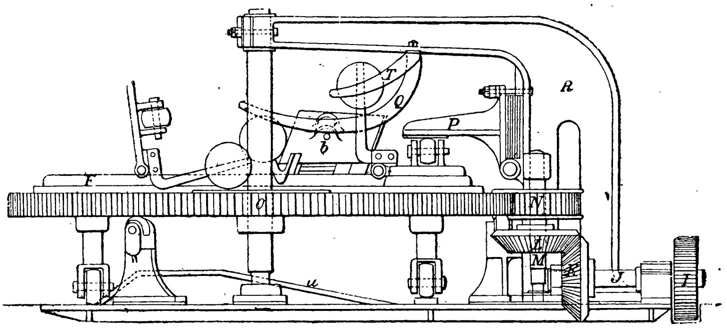
with a large wheel H, on the shaft *d*, which also carries several cams. The principal cam *i*, Fig. 476, which actuates the compressing piston *j*, is fixed in the middle of the shaft *d*; it effects successively, first the progressive compression of the material to be agglomerated in the mould; second, a final compression of short duration; and, third, the expulsion of the finished brick. Its contour is shown at *u*, Fig. 475. This cam acts on the piston *j* by means of two rollers *k k*, mounted loosely on axes carried in bearings formed at each end of the hollow cage J, which forms an extension of the piston. This is guided by pieces in the cheeks of the framing. The two outer cams *n n*, also fixed on the shaft *d*, operate on levers D, pivoted to the framing, and bolted rigidly to a vertical plate E, which serves to close the exit orifice of the mould A during pressure, and uncovers the mould when the piston advances for expelling the brick on to the bars *o o*. These bars are fixed in an inclined position. The rigid holding of the plate E during the pressure is secured by means of two supports *p p*, cast on the framing.

477.

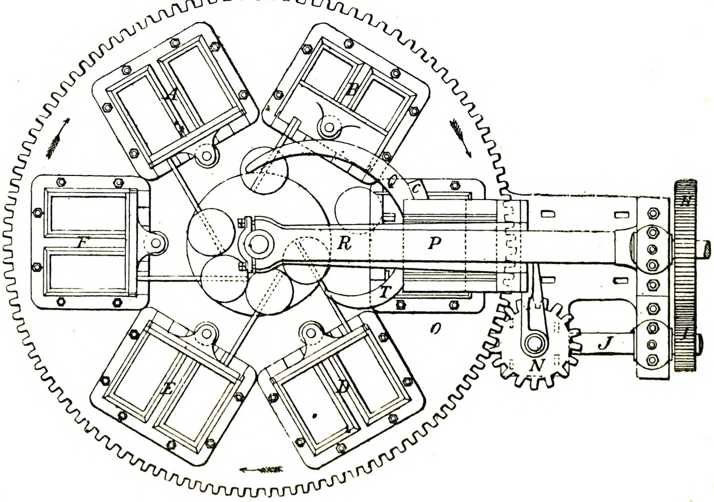


In order to prevent the bricks, when expelled from the mould, from adhering to the face of the piston, a small stirrup frame *q* is provided at the end of the machine, on to which the brick passes as it issues from the mould. This stirrup-frame is guided on either side by the framing *a*, and is connected to the plate E by means of two rods or guides *r*, passing through a projection *s* fixed to the door. These guides have screw nuts on their upper ends, so that when the door E has been raised by the action of the cams *n n*, operating on the lever D, and the brick has been entirely extruded, then by causing the door to rise a little higher, effected by small projections on the cams, the projection *s* in pushing against the nuts causes the stirrup-frame *q*, and with it the brick, to be slightly raised. The brick, being thus made to slide against the face of the piston, becomes detached. As the levers D descend with the door the stirrup frame also descends, and brings the brick again to the level of the inclined bars *o*.

478.



479.



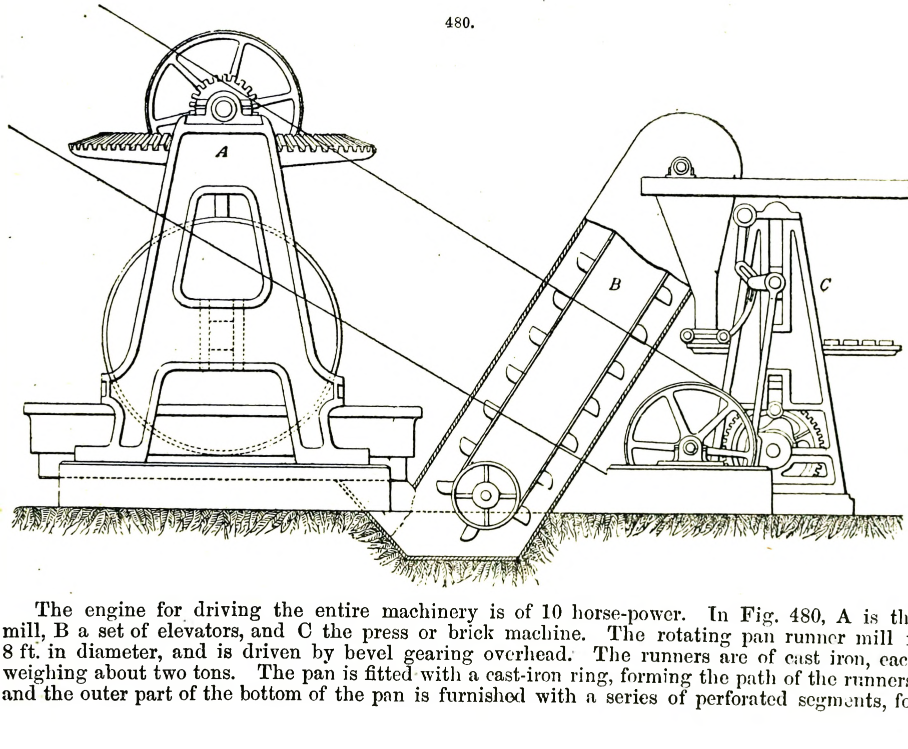
Small escape apertures are provided in the sides and bottom of the mould, also in the piston itself, to allow of the escape of any excess of earth at the time of compression, and prevent resistance. These escape apertures may be dispensed with by employing another arrangement, Fig. 477, in which a portion of the bottom of the mould, at least equal to the width of the brick, is hinged to the end of a weighted lever *v*. By increasing the weight, or by altering its distance from the fulcrum, the pressure resisted by the movable bottom, and consequently the degree of compression of the material, may be regulated. Should this pressure be exceeded the movable bottom will descend, and prevent fracture of the machine. The machine can be arranged either single or double acting. In the latter case the piston, *i*, is extended backwards, and arranged to work in a similar mould.

Stubbs' brick-pressing machine, Figs. 478, 479, as manufactured by W. G. Bagnall, consists of a revolving table, which contains six double dies A B C D E F, the table being fixed on a vertical shaft, running in gun-metal bearings at top and bottom, and supported by cast-iron anti-friction rollers on brackets bolted to the foundation plate.

The power is transmitted to the shaft, and afterwards through a pair of elliptic wheels H I to the shaft J, and off the shaft J through a pair of mitre wheels K L to the shaft M, on which is fixed a double-flanged spur pinion N, gearing into a ring cast on periphery of the table O. The pinion N is geared into the spur ring on the table in the proportion of 6 to 1, consequently, for every revolution of the elliptic wheels one die is brought under pressure when the motion is retarded; this also allows time for filling and taking off. The clay is discharged out of the pug mill, through a mouthpiece of suitable size, on to the wire-cutting table, and is there cut into blocks by an attendant, who places them in die A. As the table revolves the die is carried round, until the anti-friction roller on the bed comes into contact with curved bar Q, which is secured to the bracket R, by which the cover is shut on top of the die. The die then passes under the bracket P. Each die is provided with a sliding bottom, supported on the bedplate by lugs fitted with anti-friction rollers. While the cover is running under the bracket P, the bottom is gradually rising up the incline S, which gives considerable pressure, and brings the brick to the shape required. In the lids there are small holes to allow the air and surplus clay to pass off. This pressure is again relieved before leaving the bracket, when by the gearing of the elliptic wheels, the motion of the table is accelerated. Immediately the die passes from under the bracket P, the ball on end of the lever is caught by the curved bar T. The hinged lid is thrown open, the ball being used to counterpoise. The rollers connected to bottom of the die then run up the incline *u*, which throws the bricks above the level of the die, so that they can readily be removed by hand at die E. The bracket P is packed at the back with indiarubber, which will give way when any unnecessary strain is brought to bear on the press. This table will press 18,000 bricks a day, and is adapted for clay containing sand and other impurities. With superior clay, pressed bricks can be turned out in a semi-dry condition.

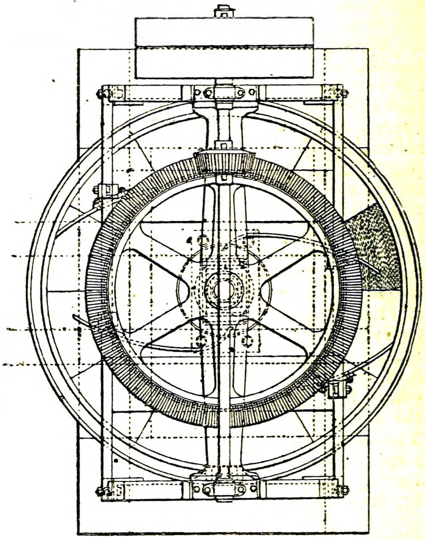
Semi-dry Brick-making Machine.—The importance of utilizing shale accompanying coal and other minerals has long been recognized. The usual and well-known process of brick making from plastic clay has been found unsuitable for the utilization of shale, or rock fire-clays. These are not softened by weathering, nor reduced to a sufficiently fine condition by ordinary preparing machinery to be expressed through dies. H. Clayton, Son, & Howlett have constructed a set of machines for making bricks from coal shale, bind, fire-clay, and other non-plastic materials. The apparatus consists of a powerful mill having a perforated bottom, and a press, both being worked by power. Fig. 480 is an elevation of the plant, Fig. 481, a plan of the grinding and sifting mill, Figs. 482, 483, side and front elevations of the brick-moulding and pressing machine.

480.



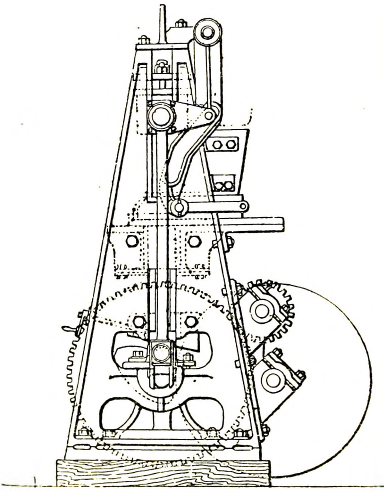
The engine for driving the entire machinery is of 10 horse-power. In Fig. 480, A is the mill, B a set of elevators, and C the press or brick machine. The rotating pan runner mill is 8 ft. in diameter, and is driven by bevel gearing overhead. The runners are of cast iron, each weighing about two tons. The pan is fitted with a cast-iron ring, forming the path of the runners, and the outer part of the bottom of the pan is furnished with a series of perforated segments, for sifting the material after it has been pulverized. The ground clay passes through the perforated plates and falls into a catcher, out of which it is swept by arms fixed to the bottom of the pans into a general receiver. The runners revolve against the motion of the pan on a horizontal shaft, carried in vertical guides at each end, and hollowed at the centre for the vertical driving shaft of the pan to pass through. The elevators consist of a band furnished with buckets, which carry the ground material from the receiver, and deliver it into the hopper of the moulding and pressing machine.

481.

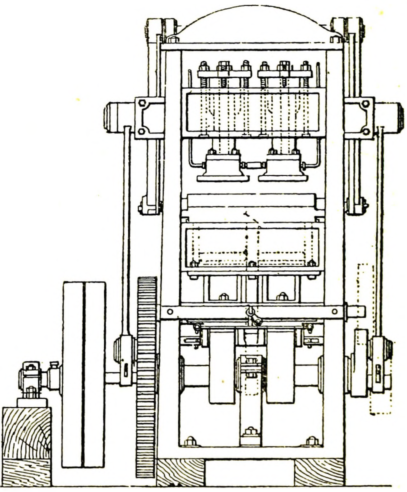


The framework of the pressing machine, Figs. 482, 483, consists of two vertical standards bolted to a cast-iron foundation plate, and connected at the top by a stretcher plate. A hollow casing or box is bolted between the side standards, and is fitted with loose linings or moulds. The lower pressing pistons are attached to a cross-bar, arranged to slide in vertical guides in the main standards, with friction rollers on the lower ends. The main shaft is driven by compound gearing, and revolves in bearings in the main framing. Upon this shaft are fixed two pressing cams, which work in contact with the rollers on the lower pressing pistons. There are two cranks on the main shaft, one at each end, with connecting rods for giving motion to the crosshead above. This crosshead slides in guides in the framing, and to it are attached the upper pistons. These pistons are hollow, and are heated by steam to prevent the material adhering to them. They are fixed upon blocks held firmly in the crosshead and have only a vertical motion. The upper parts of the blocks are made smaller, and have screw threads cut upon them. Volute springs are coiled round the screws, and plates are placed upon the top of the springs, which can be screwed down to any desired degree of compression, thus regulating the amount of pressure to which the bricks are to be subjected. There are bolts passing through the crosshead, and also through the plates, by screwing up or unscrewing which the piston can be made to descend a greater or less distance into the moulds, thus forming thinner or thicker bricks as required. Regulating wedges are placed under the lower cross-bar, and are adjusted by small hand wheels. The cross-bar when in its lowest position rests upon these wedges, so that when the wedges are drawn higher upon their seat, the pistons on the cross-bar do not descend to the full extent. Thus the depth of the moulds, and consequently the quantity of material admitted into them, may be regulated according to the nature of the material and size of brick required.

482.



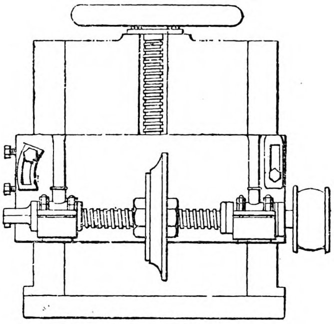
483.



The prepared material is fed into the two moulds by a self-acting arrangement. A measure or feed-box slides to and fro under the feeding hopper of the machine, and thus passes alternately under it and over the moulds, conveying each time sufficient material for filling the moulds. The feed-box is actuated by friction rollers attached to the crosshead, and in their motion with it they traverse a slotted chase, formed in each one of a pair of swinging arms, connected one on each side of the feed-box. The chase is of such a shape as to ensure the requisite intermittent and alternate motion of the feed-box. The moulds are made portable, and fit into the hollow mould casing, so that they may be easily taken out and moulds of other sizes or shapes introduced in their places. Correspondingly, the top and bottom pistons can also be removed with facility. Thus by the same machine a large variety of shapes and sizes of bricks may be produced.

In this apparatus the pressure is given simultaneously at the top and bottom of the brick, and the whole of the pressing action is derived from cams and cranks all fixed or formed upon one main shaft. The whole of the pressing strain is sustained between the lower cam shaft and the top pistons, and is virtually taken by the side arms, which are made of sufficient strength to resist the strains brought upon them. The frame is thus entirely relieved from all strain. The bricks when pressed are delivered from the moulds by the lower pistons, which are forced upwards by the complete revolution of the cams, and the newly-made bricks are moved forward by the approach of the feed-box with a fresh charge of the material. The lower pistons then fall, and the moulds are refilled ready for the next pressure. For conveying the bricks from the machine an endless travelling band is employed.

484.

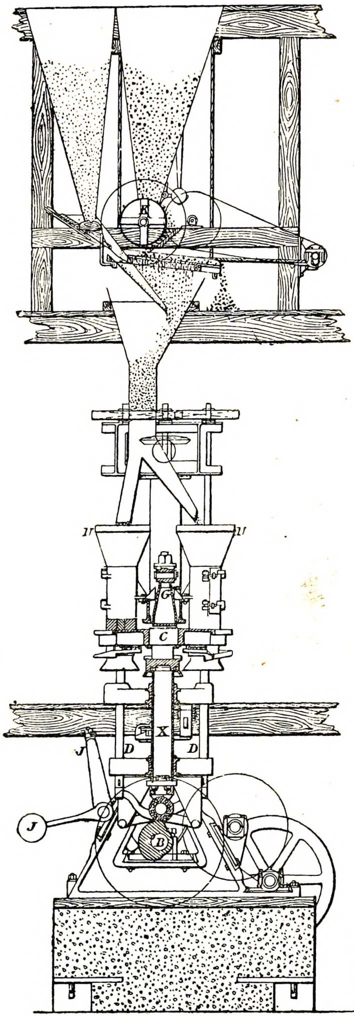


Brick-shaping Machines.—Lloyd's brick-shaping machine, Fig. 484, is for brick surfacing and moulding by means of emery wheels. The machine consists of a horizontal cast-iron base plate, carrying the vertical frame provided with a screw, by means of which the headstock carrying the spindle of the emery wheel can be raised and lowered at will. The headstock can be adjusted so as to set the spindle at various angles to undercut the mouldings, and to cut arch-bricks. To hold the brick during the process of shaping, a slide is made of wood, with a shallow box, in which the brick is fixed by means of a wooden wedge. As for various purposes bricks have to be held in different positions, and for arch-bricks at different angles, it is better not to have any permanent metal arrangement for holding the bricks, but to prepare these wooden slides whenever wanted. A piece of wood across the end of the slide serves as a rest for the hands of the labourer working the machine, and a guard over the emery wheel avoids all danger from the wheel breaking. The emery wheels are from 8 in. to 12 in. diameter, and of course of any shape for moulding or surfacing. They are run at about 1800 revolutions a minute, and one labourer passes about 1500 bricks through the machine daily. If a brick requires both surfacing and moulding, about 500 will be finished in a day. The emery wheels can be faced by friction with a piece of gas-pipe, running the wheel very slowly.

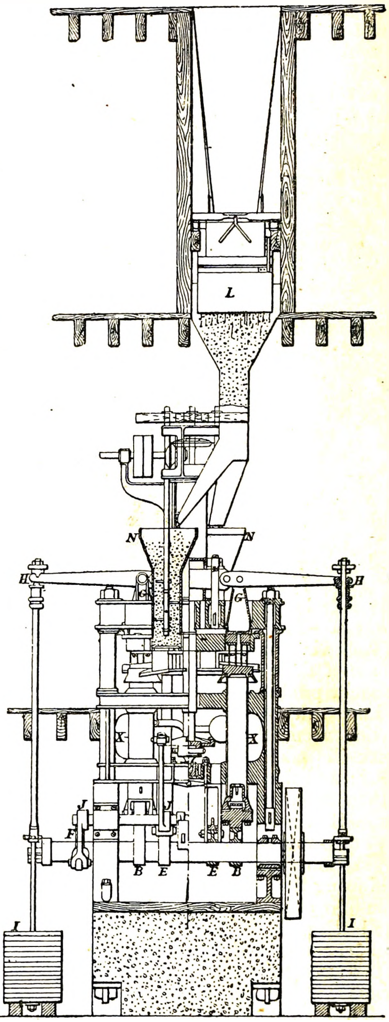
Slag Bricks.—The Cleveland Slag Company have paid considerable attention to the manufacture of bricks from slag, amongst numerous attempts to utilize this waste material, and the most important item of their production is slag bricks for building purposes. These bricks are made from the slag sand, produced by a special machine at the blast furnaces. The sand is mixed with selenitic lime with addition of oxide of iron, and is pressed in a machine to be presently described. At the commencement of operations it was found that there was no machine made in England that could work the material, in the state in which it is produced at the furnaces, without previous preparation; and this preparation to suit the brick press so increased the cost of the bricks as to exclude them from the market. It was therefore necessary to design a special press to work the sand, just as it comes from the slag-sand machines, directly into bricks. In designing this machine, the following points had to be kept in view;—great depth of moulds, because the slag sand is very spongy and compressible; an arrangement by which the water could escape from the moulds without blowing the bricks to pieces; great pressure, in order to consolidate the sand in the moulds; prevention of over-pressure; regularity in proportions of lime, and in filling the moulds.

In the brick press, Figs. 485, 486, designed to meet these requirements, the pressure is given by two cast-steel cams, fixed upon a forged steel shaft, 7½ in. diameter. This shaft, resting on bearings between two strong A frames, is put in motion by very powerful double-geared spur-wheels, the first motion-shaft carrying a heavy fly-wheel. The pressure cams B act against rollers fixed upon two steel rams X. These cams transmit the pressure to the moulds in the table C. The table is circular and contains six pair of moulds, so that four bricks are pressed at one time, the table remaining stationary during the operation. At the same time as the bricks are undergoing pressure, two other pairs of moulds are being filled with material; and the remaining two pairs are delivering up the four bricks pressed at the previous revolution of the cam-shaft. The bricks are pushed out of the mould by smaller pistons D, acted upon by the separate cams E. The moulds are lined with changeable steel plates $\frac{3}{16}$ in. thick, and the sand and lime is fed into them by two pug-mills N. These pug-mills are fitted with six knives each. The table is shifted round by a kind of ratchet motion, also worked by a cam on the outside of the framework F, and acting upon the weigh bar and levers J. Immediately above the pressure cylinders are two pressure stops G, which are held down by the heavy weighted levers H. These levers H therefore receive the whole pressure put upon the bricks, and in case there should be too much sand in the moulds, these levers rise and relieve the strain. The weights I can be weighted as required, and thus exactly gauge the pressure upon the bricks. In ordinary work the moulds are filled so as to nearly lift the levers. The filling is easily regulated by the set of knives upon the pug-shafts, which press the material into the mould C. One side of the pug-mill cylinder is removable, so that the knives are always accessible. The pug-mills are filled by means of the measuring and mixing apparatus, placed on the floor immediately above the brick press. The mixing and measuring apparatus is simple and efficient. The slag-sand is tipped into a hopper from large barrows, lifted by a hoist. At the bottom of this hopper is a revolving cylinder K, with ribs cast upon it, which, as it revolves, carries with it a certain thickness of sand, the thickness having been previously regulated to the requirements of the press. The slag then falls upon a sieve L, which separates any large pieces of slag in a solid state, and at the same time allows the falling sand to pass through the sieve. The lime is fed into a separate hopper, and its supply is regulated very much like the feed of corn into mill-stones. The lime then passes down a shoot, which forms part of the slag-sand sieve, where it meets the shower of sand, falling together with it and getting thoroughly mixed.

485.



486.



The bricks, when taken from the brick press, are placed upon spring barrows, holding fifty each. They are then stacked in sheds, where they are allowed to remain about five or six days, after which they are simply stacked outside in the weather to harden. The percentage of loss is very little, not amounting to 2 or 3 per cent. Each machine is capable of turning out 10,000 bricks in a day.

The following are a few of the advantages of these concrete slag-sand bricks. Being pressed, they are perfectly uniform in size and thickness; they are much cheaper than ordinary red bricks, compared in weight with which they are 1 ton a thousand lighter; there are no wasters nor halves; nails can be driven into these bricks without splitting them, saving plugging in the walls for skirting and doorwork.

Bricks.—A brick is a quantity of clay, mixed with sand, pressed in a mould, dried in the sun, and nearly always baked by fire. Bricks may, however, be divided into those dried in the sun, and those baked or hardened by fire. Sun-dried bricks have no extensive use except in equatorial countries, and to impart to them sufficient durability, it is necessary to cover them with an impermeable compound of lime and clay. Burnt bricks may be divided into refractory or fire-clay bricks and ordinary bricks. Refractory or infusible bricks are made from clays containing neither lime nor oxide of iron, and are employed in the construction of furnaces and apparatus intended to withstand high temperatures. Ordinary bricks are rectangular parallelopipeds, varying in dimensions according to locality and purpose of manufacture.

The following are some varieties of ordinary bricks. Air-bricks pierced with holes to allow of the passage of air. Arch-bricks, partially vitrified bricks from the arches of the clamp or kiln in which the bricks are burnt. Capping bricks, shaped for the upper course of a wall. Clinkers, bricks taken from the arch of a clamp and of glassy structure. Compass bricks are voussoir-shaped for arches. Coping-bricks, shaped or selected bricks for coping courses. Feather-edged bricks, with bevelled edge for vaults and arches. This term is also applied to bricks of prismatic shape, for building on the skew. Stocks, grizels, and the like are local terms applied to various qualities of bricks.

The average specific gravity of well-made bricks is 1·841; a cubic foot weighs 115 lb. and absorbs $\frac{1}{16}$ of its weight of water. The force required to crush an ordinary brick is about 500 to 550 lb. a square inch.

Bricks should be made with clays of the best quality, properly blended. They should be sharply and perfectly moulded, without breakage or cracks, well-baked, but not burnt; they should be hard, compact, tenacious, and of fine grain. Their further characteristics and uses in construction will be found described under the heads "Construction," "Bond," and "Brick Machinery," in this Dictionary.

Brick-earth or common clay should be neither too rich (fat) nor too poor, that is, neither too clayey nor too sandy. The richer clays, which contain too much alumina, are plastic, and subject to deformation during drying and baking. The remedy for this is the addition of silica or sandy matter which imparts greater closeness. Too poor clays, or clays too highly charged with silica, dry easily, but make porous and absorbent bricks, friable and of low strength. These bricks never acquire satisfactory durability by baking. The remedy is the admixture of a proper quantity of fat clay, such as Kimmeridge clay. Brick-earth should contain no small stones that can interfere with the homogeneity of the worked clay, nor substances susceptible of decomposition during burning, such as iron pyrites, flints, or limestone. The finest earths do not always furnish the best products, but the clay in any case should not contain fusible substances, because the bricks would then vitrify during baking. The best method of determining the qualities of a clay is by trial upon a small scale. To this end some bricks are prepared which are allowed to dry slowly, and then submitted to burning in a lime-kiln.

Ordinary brick earths have for chief constituents alumina and silica, in combination with lime, magnesia, or iron. But chemical analysis does not assist the brickmaker in determining the value of an earth for his purpose, because it does not account for the mechanical conditions of the constituents, for instance whether the silica exists as sand or as a combined silicate. In whatever state the constituents may be, their chemical effect during firing or burning is similar.

Alumina imparts to clay its plastic properties, but a brick containing too much alumina warps or cracks in drying, and becomes very hard during burning.

Silica, in the presence of alumina only, is infusible at ordinary temperatures, but the presence of a small quantity of oxide of iron, which acts as a flux, renders the alumina and silica fusible at a low temperature. Sand prevents cracking, shrinkage, or warping. and provides the silica necessary for partial vitrification; the larger the proportion of sand, the more homogeneous the structure of the brick. But excess of sand causes brittleness.

Lime lessens the contraction of the bricks in drying, and acts as a flux upon the silica during burning. Excess of lime renders the brick too fusible. Lime, when present, must be in impalpable powder, because during burning, the lime, if occuring as limestone, decomposes, and the carbonic acid given off splits the brick, or the quick-lime formed also splits the brick when wetted. Bricks containing lime should be well-soaked before use.

Oxide of iron, besides rendering silica and alumina fusible as described, affects the colour of the bricks, producing tints varying from light yellow to deep red. When there is 8 per cent. or more of oxide of iron, and when the brick is submitted to fierce firing, the red oxide is converted into black oxide, which fuses with the silica, imparting a dark blue or purple colour. Lime with iron in small quantities produces a cream-coloured brick; increase of iron produces a red, and of lime a brown colour. In red-bricks oxide of iron is presesent in large percentage, but not fused. In the presence of iron, magnesia imparts a yellow colour to the brick; and manganese darkens the colour that iron imparts to a blue brick.

Iron pyrites is a very prejudicial, though common, constituent of clay; it is partially decomposed during burning, then oxidizes in the brick, producing so-called flowery bricks, and causing splitting.

Common salt, sodium chloride, acts as a powerful flux, and only the commonest bricks known as place bricks, can be made from clay containing much salt. The hygroscopic nature of salt always causes the brick to be strongly absorbent of moisture.

Chalk is added to some clays to produce white bricks.

Brick earths may be thus divided;—

Plastic, fat, or strong clays, composed chiefly of silica and alumina, with small proportion of lime and other constituents, excepting iron.

Loams or mild clays, sandy clays.

Marls, calcareous, or chalky clays.

Malm, an imitation of natural marl, is compounded of clay and chalk, the operation being generally performed in a wash-mill.

Good brick-earth should contain sufficient flux to bring its constituents into fusion at furnace heat. A greater quantity of flux will cause the bricks to become vitrified or glazed. The best earths contain 20 to 30 per cent. of alumina, and 50 to 60 per cent. of silica. The bricks made from such earths are a silicate of alumina with silicate of lime or other flux, and depend for quality on the selection and mixing of the clay.

Pure or fat clays are sometimes used without any addition, and the sand contained is then usually sufficient to prevent too much contraction. These clays during baking do not become sufficiently fused to thoroughly agglomerate the mass, and therefore do not so well withstand weathering as a partly vitrified brick. Clays of this character are consequently improved by the addition of silica in the form of sand, with lime to act as a flux. Instead of lime, ashes are used to yield alkalies as a flux. Marls are best suited for brickmaking direct from the clay without admixture.

Good building bricks should be free from cracks, flaws, stones, or lumps of any kind, regular in shape and uniform in size. The edges, or arises, as the edges are termed, should be square and sharp. Hollow surfaced bricks are to be avoided; the surface should be flat and not too smooth. Badly burnt bricks absorb a larger quantity of water, and soon become rotten. Average bricks absorb generally about 16 per cent. of their weights of water; only highly vitrified bricks absorb as little as $\frac{1}{15}$ of their weight as is generally stated in text books. Thoroughly hard-burnt bricks have a metallic sound when struck together; a dull sound is generally indicative of soft or cracked bricks.

Clamp, or kiln-burnt, and machine-made bricks are easily to be distinguished. Traces of breeze are to be found in clamp-burnt bricks. Kiln-burnt bricks have sometimes coloured stripes upon the sides, caused by the arrangement of the bricks in the kiln. Machine-made bricks are to be distinguished, either by the marks of the cutting wires, by the peculiar form of the mould, or by having a frog, or hollow, on both sides.

Ordinary London bricks are about 8¾ in. long, 4¼ wide, and 2½ thick. The weight of a brick is about 7 lb. These dimensions are very slightly departed from, but in Scotland and the north of England bricks are larger and heavier. To obtain good bonding in brickwork, the length of each brick must exceed twice its breadth by the thickness of a mortar joint.

The following tables give the size and weight of the most used varieties of bricks in England, and the resistance of these varieties to compression; the authorities are chiefly Latham and Grant.

TABLE OF SIZES AND WEIGHTS OF VARIOUS KINDS OF ENGLISH BRICKS.

Description.	Dimensions.	Weight.	Weight a 1000.
	inches.	lbs.	cwts.
London stock	8·75 × 4·25 × 2·75	6·81	60·75
Red kiln	8·75 × 4·25 × 2·75	7·0	63
Fareham reds	8·5 × 4·15 × 2·6	6·3	56·2
,, rubbers	10·9 × 4·8 × 2·9	8·8	78·5
Lancashire red brick	9 × 4·5 × 3	8·9	80
Leeds pressed brick	9·5 × 4·5 × 3·5	10	89
Sandyfauld Scotch brick	9·5 × 4·5 × 3·5	9·7	86·6
Glasgow bricks	9 × 4·3 × 3·4	8·6	77
Burham wire cut	8·6 × 4·0 × 2·6	5·4	58·2
,, pressed	8·75 × 4·2 × 2·7	6·1	54·5
Suffolk brimstone	9 × 4·6 × 2·6	6·8	60·7
,, white	9·2 × 4·3 × 2·6	6·3	56·2
Staffordshire paving	9 × 4·5 × 3	8·9	80
	9 × 4·5 × 2	6·1	55
,, edge-paving	9 × 3 × 3·5	7·8	70
Tipton blue	9 × 4·5 × 3	10	89
Adamantine clinker	6 × 2·5 × 1·75	2	18
Dutch ,,	6·25 × 3 × 1·5	1·55	14

RESISTANCE OF BRICKS TO COMPRESSION.

Description.	Dimensions.	Area exposed to Crushing.	Average Weight under which Brick Cracked.	Average Weight required to Crush Brick.	Weight required a sq. in. to Crush Brick.
	inches.	sq. in.	tons	tons	tons
Unburnt brick	8·9 ×4·4 ×2·9	38·8	1·0	9·0	0·23
Common red	9·0 ×4·3 ×3·0	38·7	9·5	57·0	0·96
Machine ,,	9·3 ×4·4 ×3·3	40·9	23·0	33·0	0·79
Common stock	8·9 ×4·0 ×2·5	36·2	10·0	128·0	3·56
Sittingbourne stock	8·8 ×4·13×2·5	36·3	5·7	33·9	0·93
Fareham reds	8·5 ×4·25×2·6	36·1	8·4	26·1	0·72
,, rubbers	10·2 ×4·8 ×2·9	49·6	1·4	15·7	0·32
Tipton blue	8·75×4 3 ×2·5	37·7	21·3	95·2	0·39
Exbury best	8·8 ×4·25×2·75	37·7	21·0	28·5	0·76
,, seconds	8·8 ×4·25×2·75	37·7	21·0	39·0	0·77
,, thirds	8·5 ×4·1 ×2·6	35·1	11·3	29·0	0·83
Suffolk brimstone	9·0 ×4·56×2·7	41·3	5·1	31·0	0·77
,, best whites	9·2 ×4·56×2·6	41·9	5·1	19·6	0·47
Gault	8·75×4·25×2·75	37·2	12·7	35·1	0·94
,, wire-cut	8·6 ×4·0 ×2·6	34·5	6·4	32·9	0·95
,, ,, white	9·0 ×4·3 ×2·7	39·1	11·0	53·0	1·35
Pressed gault	8·9 ×4·3 ×2·7	38·2	8·0	46·5	1·23
,, ,,	8·75×4·19×2·7	36·6	7·4	36·8	1·00
Staffordshire dressed blue	9·0 ×4·5 ×2·97	40·3	15·5	114·0	2·80
,, pressed ,,	8·9 ×4·5 ×2·9	39·8	21·5	73·0	1·86
,, common ,,	9·4 ×4·4 ×3·0	41·1	13·0	39·0	0·95
,, bastard	9·2 ×4·6 ×3·2	41·2	27·0	41·5	1·01
Brown glazed brick	9·0 ×4·4 ×3·4	39·5	16·0	23·0	0·58

Besides the descriptions of bricks already detailed, there are the following varieties and sub-varieties;—

Splits, or split-bricks, are reduced in thickness to the dimensions of 9 in. by 4½ in. by 1 in, 1½ or 2 in. Soaps are about 9 in., by 2¼ in. wide, by 2¼ thick, and sometimes pierced for ventilating.

Cutters, or rubbers, are bricks intended to be shaped by cutting or abrasion to some required pattern. These bricks are made soft, generally of washed earth, freed from lumps, and of uniform composition. These bricks are not allowed to vitrify in the kiln, and in inferior qualities the firing is too early discontinued, so that the bricks have no cohesion, and are quickly destroyed by rain and frost. In all cases where the work is exposed to the influence of the weather, purpose-made, or specially formed bricks, should be employed, because the vitrified surface prevents penetration of moisture.

In Kentish brick-fields, bricks are generally divided into three classes; malms, washed, and common, the difference being determined by the mode of preparing the earth. For common bricks the earth is not washed. All are moulded and burned in the same manner, and are sorted after burning.

Shippers are bricks deformed in burning, chiefly used to ballast vessels, in order to export bricks at small cost.

Stocks, bricks hard burnt, but inferior to shippers, chiefly used for ordinary work. Hard stocks are overburnt, having defects in form and colour, but otherwise sound, chiefly employed in the body of thick walls.

Grizels, or grizzles, are underburnt, have little coherent strength, and from the stones contained are very liable to fracture. These bricks are used for very inferior or temporary work, and when used for permanent structures are always coated with cement.

Chuffs are useless bricks upon which rain has fallen, while the bricks were hot.

Burrs are lumps of vitrified brick earth, as may be seen in artificial rockwork or grottoes, obtained from the fusing of the bricks nearest the fire in the kiln or clamp.

Bats are half or broken bricks.

White bricks are best made from refractory clay and a fine white or yellow sand; this clay burns white, and the sand vitrifies at a high temperature. Every clay containing not more than 6 per cent. of iron, when mixed with chalk, will yield a white brick, but care must be taken that the clay is strong enough to allow of sufficient admixture of chalk. White bricks are best burnt in close kilns to prevent deposits of soot; they must be allowed to cool gradually, or they crack. White bricks being made from clays of high specific gravity are generally perforated or constructed hollow. Irremovable green stains occur on underburnt white bricks, which can be remedied by painting the brick with a wash of the same brick clay, made with a solution of blue copperas, allowing this wash to remain on the brick until dry, then rubbing off with a hard brush.

Gaults are white bricks made from a bluish tenacious clay occurring between the Upper and Lower Greensand formations. This clay contains sufficient chalk to impart a white colour to the brick as well as to act as a flux. These bricks are of superior durability and hardness, but are very heavy, and for the latter reason are generally perforated or constructed with a deep frog. Suffolk whites are also made from the Gault clay, and are good rubbers, as they contain a considerable proportion of sand. These bricks harden by time, this hardening being probably due to the silicic acid of the clay combining with the lime gradually to form silicate of lime.

Exbury, or Beaulieu, bricks, are made from the white clay occurring on the banks and bottom of the Beaulieu river, near Southampton. These are white bricks and are largely used for facing.

Staffordshire bricks are, as their name implies, made from the Staffordshire clays. These clays and marls contain 7 to 10 per cent. of oxide of iron, consequently the bricks are blue-black in colour. These bricks are impervious to water, resist great pressure, and are very durable. They are imitated by washing over inferior bricks with a solution of iron.

Dust bricks are made with coal dust instead of sand, and are vitreous and durable.

Fareham reds are from a plastic clay occurring in the deep beds around Fareham, are very superior bricks, but should not have the surface removed by rubbing. These bricks were extensively employed for the facings of St. Thomas' Hospital, London.

Nottingham dry clay bricks are made by the dry clay process, and generally burnt in Hoffman's kilns. Part of St. Pancras Station, London, is constructed with these bricks.

Dutch clinkers are small, thoroughly vitrified bricks, chiefly used for pavings.

Salted bricks have a glaze produced upon their surface by throwing salt upon the fires during burning.

Concrete bricks are simply blocks of concrete, details of which will be found described under the head of Concrete. The following remarks upon the preparation of brick-earths, whether for moulding by machine or hand, will complete the information on this branch.

When the clay is very hard, marly in character, containing lumps of race or limestone, it is ground between iron rollers.

Malm is dug in the autumn. It is at once conveyed, with due proportion of ground chalk, to the washmill. The chalk averages about 6 per cent. of the clay. This mixture is reduced to a thick cream, and is then run off into backs or shallow tanks, where it remains until nearly solidified. It is at this stage soiled, or covered with about $\frac{1}{6}$ of its depth with screened cinders, and allowed to remain for weathering throughout the winter; after this the backs are dug out, and the clay and ashes pugged together. This method of preparing malm is known as washing.

The quantity of clay required for 1000 ordinary bricks varies from 1½ to 3½ cubic yards, as measured before digging, the stronger clays requiring to be in the greater quantities.

Hand Moulding.—The dimensions of the moulds are such as to allow for the contraction of the clay in burning, the linear measurements being from 8 to 10 per cent. more than in the finished brick. The superfluous clay is removed from the mould by a piece of wood or steel, termed a strike. In slop-moulding the brick is frequently dipped into water, to prevent adhesion of the clay.

Sand is also used for this purpose; the process is then termed sand-moulding, and there is produced a cleaner and sharper brick.

As each brick is passed from the hands of the moulder, it is either carried by a boy, still in the mould, to the drying shed, the moulds being returned, or it is deposited upon a pallet-board, which is removed upon a hack-barrow, mounted on springs and running upon smooth wrought-iron wheeling plates, so as not to shake the brick.

To secure the mould upon the stock-board, whilst in the moulder's hands, this board has a projection, which forms the hollow in the brick, termed the frog or kick. This hollow serves as a mortice into which the mortar can key. Bricks are laid with the frog uppermost. Wire-cut bricks are without this hollow.

In drying, the bricks are placed upon hacks, long parallel banks raised about 6 in. from the ground, and built of dry brick rubbish and ashes. They should not be more than eight courses in depth, or the lower may be crushed. When the bricks are semi-dried they are scintled, or placed diagonally at small distances apart to allow of the passage of air. In this stage the lower course will admit of twelve or thirteen courses being placed upon it without crushing. Raw bricks generally require about ten days to dry before they can be scintled, when they remain for another month.

Pipe-making Machines.—The characteristics of the machines for the manufacture of drain-pipes, and other pipes made of burnt earth, are very similar to those of brickmaking machines. The manufacture of pipes includes several operations; the preparation of the earth, moulding, drying, and burning.

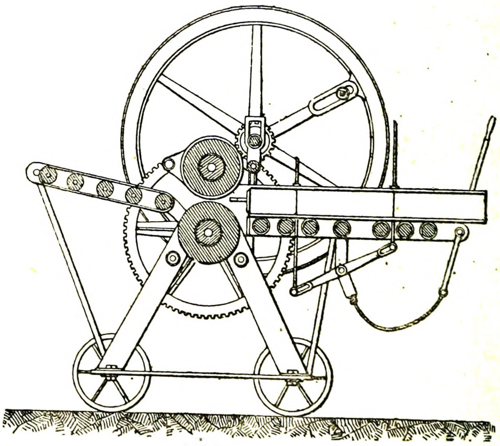
Preparation of the earth.—All kinds of argillaceous earth, from ordinary brick-earth to plastic clay, can be employed in the manufacture of drainage pottery, under conditions of convenient preparation. It is especially important that the moulded clay should be homogeneous, highly tenacious, and should not contain stones nor any foreign substance likely to interfere with its passage through the machine. This is attainable by hand operations with great difficulty and expense, and is best effected with the aid of machinery. A field having been selected as accessible as possible, the vegetable earth or surface soil is removed for about 16 in., and the clay removed. This operation is usually performed in autumn, and the clay is allowed to weather during the winter. Manufacture commences in the spring. The clay is passed between rollers which are about $\frac{1}{8}$ in. apart. It is then thrown into a pug-mill, and worked into a condition suitable for moulding.

Drying.—After moulding, presently to be described, the pipes are dried under covered sheds, in racks. When the pipes are half dried, they are rolled, if necessary, to maintain their cylindrical form.

Burning.—The burning usually takes place in kilns, which will be found to be described under the proper heading in this Dictionary, page 2178, and in subsequent pages.

Moulding.—Machines for the manufacture of drainage tubes have their origin in the old system of presses employed, in several countries, for the manufacture of white-ware tubes used for water-conduits. These presses consist of a vertical cast-iron cylinder in which is put the prepared clay. A piston, actuated by a screw, strongly compresses this clay paste, and forces it out through an annular orifice, to form the pipe. In nearly all the systems designed for the manufacture of drainage pipes the press is preserved, but the number of orifices have been increased, with considerable effect upon the production. Finally the whole system was rendered portable, of course with great practical advantage. These machines may be classed as continuous and intermittent machines.

487.

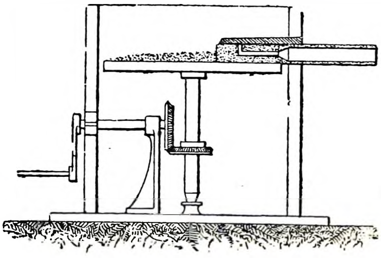


An example of a continuous machine is that of Ainslie, Fig. 487, consisting of two cast-iron cylinders to which rotary motion of opposite directions is imparted. A toothed wheel is mounted on the axis of the lower cylinder, gearing with a solid pinion, carrying a fly-wheel and crank-handle. At one end of the cylinders each has a toothed wheel in gearing, to produce the opposite rotary motion. The carrier is an endless band, moving on rollers, arranged in the rear of the machine, from which the clay is continuously fed under the cylinders by a workman. In front of the cylinders is a box of which the rollers form one side, the clay issuing by orifices on the other side. As the pipes issue from these orifices or dies, they are carried forward on an endless band, and are cut to the required length by brass wires drawn transversely. This machine is one of the earliest forms of pipe-making machines in which hand power is employed, and requires the assistance of four men and several boys.

Champion's machine, Fig. 488, consists of a circular horizontal plate about 4 ft. 6 in. in diameter, pivoted upon a base and receiving rotary motion from an axle, with pinion or crown wheel. Above the plate is a draw tube, carrying at its centre an iron arm terminated by a cone which imparts to the manufactured pipe its inner bore. A bottomless box or cover is fixed above the horizontal plate, and one of its vertical faces forms a radius to the plate, with a space of about $\frac{1}{8}$ in. between the lower edge and the face of the plate. The clay placed upon the circular plate is drawn by the rotary movement, and strongly pressed against the vertical side of the box, and being forced to escape beneath this vertical partition to the moulding nozzle, is cleared from stones.

All intermittent machines intended for the manufacture of drainage tubes are based upon the same principle. A piston, actuated by a rackwork and pinion, compresses the paste in a cylinder or box, and forces it to issue by the dies. The differences are in the number of cylinders and the position of the charge.

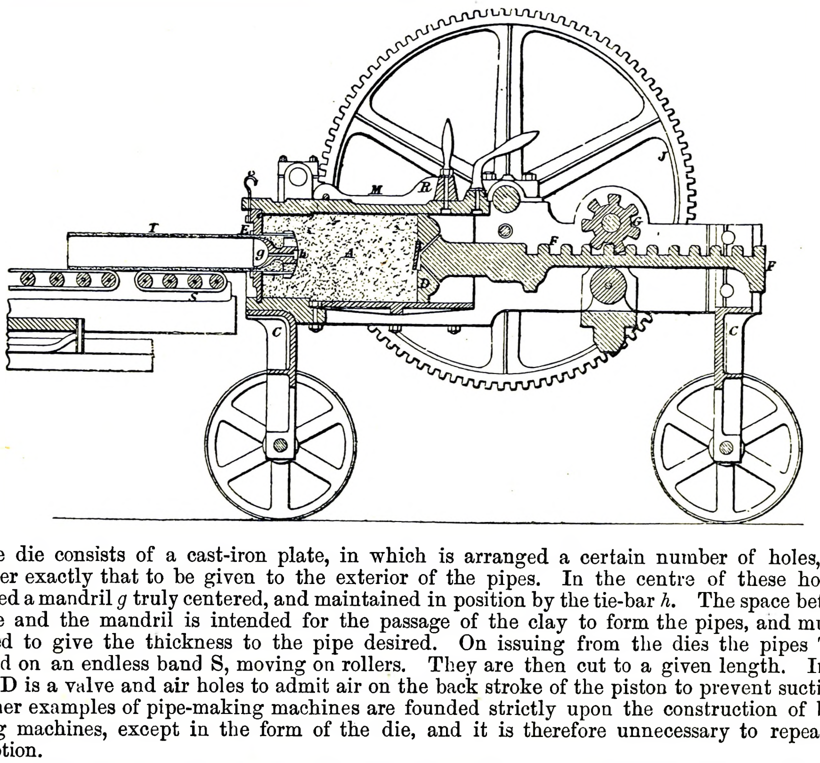
488.



Clayton's machine consists of two vertical cast-iron cylinders alternately brought into work, in which pistons strongly compress the clay through the moulding nozzle. This machine so closely resembles the brick-making machine, being indeed a brick machine applied to another purpose, as to render detailed description unnecessary.

Sanders' and Williams' machine consists of a rectangular box A, Fig. 489, mounted between heavy sides B, on a base C, on wheels. The two ends of the box are open, except that one receives the piston D, and the other the system of dies E. This arrangement admits of replacing the dies by a sheet of iron, pierced with holes for the purpose of cleaning the earth from stones. To maintain the dies in position, a keyed pin *c* is employed, with a groove which engages the lower end of the die plate. The piston consists of a head and a rack bar F, actuated by the pinion G and the wheel J and intermediate gearing. In order to introduce the clay into the box A, a lid M is provided, raised by means of a handle, and clamped with a sliding nut R.

489.



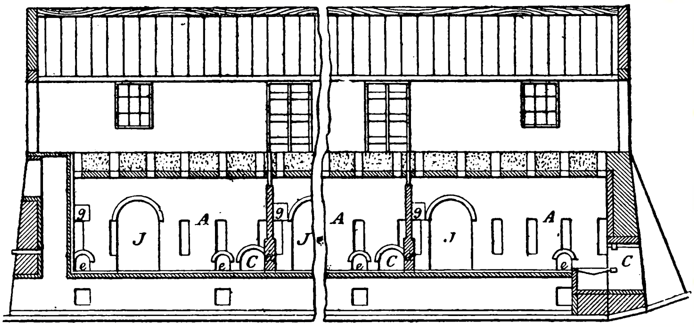
The die consists of a cast-iron plate, in which is arranged a certain number of holes, of a diameter exactly that to be given to the exterior of the pipes. In the centre of these holes is arranged a mandril *g* truly centered, and maintained in position by the tie-bar *h*. The space between the die and the mandril is intended for the passage of the clay to form the pipes, and must be adjusted to give the thickness to the pipe desired. On issuing from the dies the pipes T are received on an endless band S, moving on rollers. They are then cut to a given length. In the piston D is a valve and air holes to admit air on the back stroke of the piston to prevent suction.

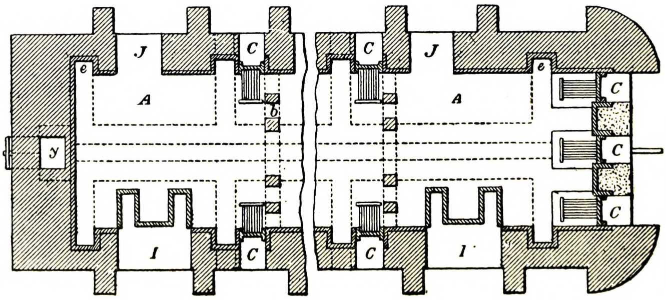
Other examples of pipe-making machines are founded strictly upon the construction of brick-making machines, except in the form of the die, and it is therefore unnecessary to repeat the description.

Barrows and Conveyance of Materials—The barrow is indispensable in the brickfield, both in the form of the ordinary wheelbarrow, which it is unnecessary to describe here, and in the form specially adapted for the conveyance of the moulded brick to the air-drying galleries, and thence to the kiln. A barrow of this latter form consists, as does an ordinary barrow, of a body with two handles, generally the extension of two branches or horizontal supports, the anterior extremities of which carry between them a wheel. The ordinary barrow generally used for the conveyance of the clay in the brickfield weighs 40 to 50 lbs., and will contain one-thirtieth to one-twentieth of a cubic metre of earth. The English form of wheelbarrow is preferred in general use, even on the Continent, as being more easily discharged of its load. Whatever the kind of barrow, the load is carried partly by the wheel and partly by the arms of the wheeler. On horizontal ground, with a barrow of ordinary proportions, the workman supports one-fifth to one-third of the total load, and the wheel supports the remainder. The effort necessary to push the barrow is equal to the weight resting on the wheel, multiplied by the coefficient of friction of the wheel on the earth, and increased by the friction of the axle. The coefficient of work is greater, on the same soil, than with carriage wheels, which are of much greater diameter. When the plane or path is sloped, the labourer brings his hands nearer to the body of the barrow, and supports a greater fraction of the weight, diminishing by as much the load upon the wheel. The reduction in the effort of pushing thus obtained partly compensates for the increased work due to gravitation down the inclined plane. Practice, in accordance with the indications of reasoning, modifies the form of the felly of the wheel with the nature of the surface on which it is to roll. If the soil is soft, the felly is made broad; if to be wheeled over a board, the felly, or even the whole wheel, may be of cast iron. It may be estimated that a common barrow will convey 60,000 to 70,000 loads, and traverse 1500 to 2000 miles, before becoming unfit for service.

Brick-kilns.—Morand's kiln, for burning all kinds of firebricks and fireclay goods, consists of a tunnel-shaped building of brick, divided into chambers by partition walls, each chamber containing usually about 10,000 bricks. Along the whole length of the kiln and above the arch are placed steam flues, communicating with each chamber by means of side dampers, and with the chimney at the end of the kiln. Underneath the kiln, and forming the base of the side walls, are the heating flues, also communicating with each chamber separately and with the chimney. Both steam and heat flues are provided with dampers in convenient positions. The steam or upper flues are used for carrying off the steam, during the process of drying the bricks with the surplus of heat from the burning chamber, or the heat produced by the fires when the kiln is first started. The heat or lower flues are to allow of the conveyance of the heat from any one chamber to any other chamber, at the will of the burner, for drying or steaming dry green bricks either backwards or forwards, the necessary draught for drawing back the heat being given by the steam flues above, which are in direct communication with the chimney. Each chamber is provided with two side fires, one at either side, and holes or openings for the ingress and egress of the bricks. The partition walls are provided with wickets for the passage of the heat directly from chamber to chamber. These wickets are temporarily blocked up with bricks, which are readily removed from the side fireholes. The large opening in the centre of the partition wall is to allow of the stacker placing the bricks regularly from one end to the other, and is bricked up when the chamber is full. The top of the kiln is flat, and provided with small round stokeholes, through which the dust coal is fed in small quantities into the chambers below. The surplus heat from the first chamber, when all the steam is driven off, is passed forward into the second, to steam the bricks in advance before escaping into the steam flue. When the last chamber is reached the heat is brought back, through the lower or heat flues, into the first chamber to partially dry the bricks therein, before passing into the steam flue, and thence to the chimney. The end fires are again lighted, and the operation continued as before. By this arrangement the advantages obtained are, that the bricks in each chamber are thoroughly steamed separately, the steam escaping by means of the top or steam flues before the heat is allowed to pass into the following chamber, which is a most important feature in burning fireclay.

490.

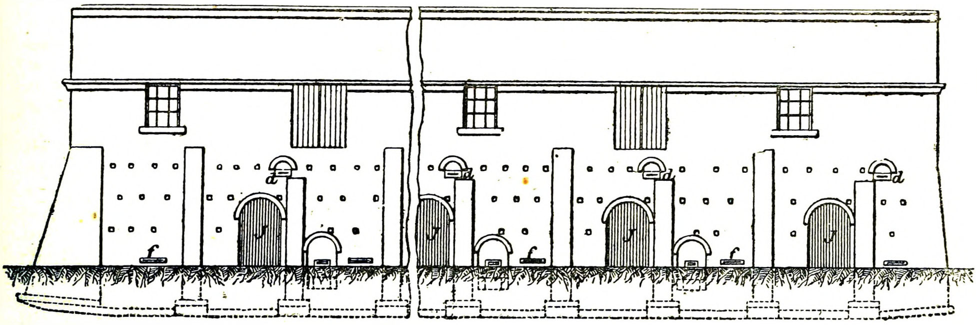




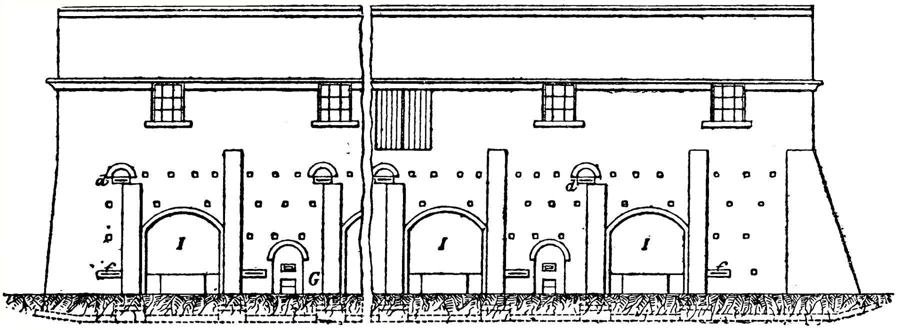
491.

In this way a good colour is obtained, and the risk of crushing down the bricks in advance is entirely avoided. Also, there is facility afforded by the combination of the steam and heat flues, for bringing back the heat from any given chamber to any other chamber, in which it may be used for drying the bricks in the kiln itself, resulting in a considerable saving in fuel, the gases escaping to the chimney being nearly cold. In Figs. 490 to 493, Fig. 490 is a longitudinal section, Fig. 491 a plan, Figs. 492, 493, back and front elevations of this kiln. A A are the drying and burning chambers, C fireplaces, D stoking-holes, G smoke or steam flues connecting the other flues and the chambers with the chimney. I I are the temporary openings for carts for removing the bricks, and J J temporary openings for setting the bricks. *a a* are division walls separating the burning and drying chambers; *b* temporary openings in these walls; *d d* are horizontal dampers connecting the chambers with the steam flues; *e e* are short passages connecting the flues with the chambers, *f* dampers controlling communication through these short passages. *g g* are passages from the chambers to the steam flues, closed when required by the horizontal dampers *d*, and the vertical dampers *h*; there are also holes to allow steam to escape when the kiln is first used; *y* the damper connecting the horizontal flues with the chimney.

492.



493.



BRIDGE.

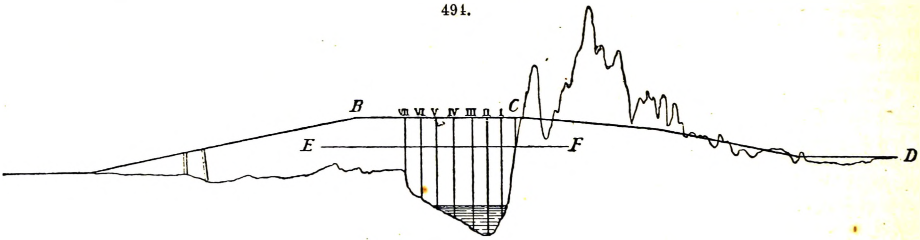
The materials of which bridges are usually constructed have been already enumerated in the article on Bridge in this Dictionary, with the exception of steel. Hitherto, this has not attained that degree of prominence in bridge building which has been accorded to it in the construction of boilers, the manufacture of rails, and the building of ships. Recently, however, a few notable examples of the erection of steel bridges, on a very large scale, have presented themselves. To these, as well as to the numerous points having a practical bearing upon the subject, we shall more particularly direct attention in the present article, and the information which it contains is that which is derived from the study of the description and analysis of existing bridges, and not of those which have never passed the limits of the drawing office.

There are certain data indispensable for proceeding with the general design, or determining the main features of any bridge; these, as will be seen, affect in a greater degree the foundations and substructure than they do the superstructure, although the latter is not by any means independent of them. In many instances, it is entirely at the option of the engineer whether he employ a cast or wrought-iron girder, and the particular form or type of the girder depends, frequently, altogether upon his own judgment.

The plan of the site of a bridge, including the number and position of the abutments and intermediate piers, supposing the bridge to have more than one span, depends upon several conditions, which have to be carefully attended to. The desiderata are minimum cost and interference with existing roads, rivers, canals, or railways, as the case may be. In the instance of a railway viaduct traversing a valley, the engineer, by a series of trial calculations, determines at what particular span, generally between the limits of 30 feet and 100 feet, the combined cost of piers and superstructure is a minimum. In the case of a river, the spans are determined similarly in some instances, and very differently in others. Thus it may be essential to avoid any interference with the navigation interests, even when this course occasions a greatly enhanced cost, as such a reason, amongst many, frequently entirely outweighs mere economical considerations. Sometimes natural advantages present themselves in the line of the proposed structure, upon which to erect intermediate supports or piers, and occasionally, but rarely, there are existing piers upon which to carry a bridge, or a portion of it, as in the railway bridge over the Thames at Charing Cross, where two brick piers, which originally supported the towers and chains of the old Hungerford suspension foot-bridge, were utilized, as already described in the article Bridge.

Sections.—A longitudinal section of the site, sufficiently extensive to include the approaches to the bridge, is equally necessary as the plan. The character of the section, together with the borings, will give the depth of the foundations and the height of the superstructure. This is evident from an inspection of Fig. 494, which represents a longitudinal section of the site and approaches of the Kansas city bridge. The line B C D is the gradient of level of the railway, E F shows high-water mark, and the position of the piers is shown by the thick vertical lines. One or more cross-sections should also be made at right angles to the centre line of the bridge, where the abutments and wing walls are situated, in order to determine the length of the latter, as will be seen further on.

494.



Foundations.—The subject of Foundations has been already treated of. See articles Construction, Bridge, Railway Engineering, Docks, Water Works. But there are a few practical points in connection with it, which we shall notice, as well as give a description of the principal methods of sinking cylinders under water.

We are indebted, with the exception of a few additions, to Jules Gaudard's remarkable paper on Foundations, presented to the Institute of Civil Engineers, in 1876, for the following particulars.

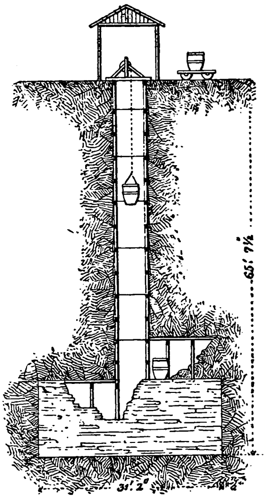
To ascertain the nature of the soil on which the foundations are to be laid, borings are generally taken, but they sometimes prove deceptive, owing to their coming on chance boulders, or upon adhesive clays which without being firm, stick to the auger, and twist it or arrest its progress, and the specimens brought up, being crushed and pressed together, look firmer than they really are. To remedy these defects some engineers have adopted a hollow boring tool, down which water is pumped and reascends, by an annular cavity between the exterior surface of the tool and the soil, with such velocity that not only the detritus scraped off by the auger, but pebbles also are lifted by it to the surface. This process is rapid, and the specimens, which are obtained without torsion, preserve their natural consistency.

On stiff clay, marl, sand, or gravel, the safe load is generally from 55 to 110 cwt. on the square foot, but a load of 165 to 183 cwt. has been put upon close sand in the foundations of the Gorai Bridge, and on gravel in the Loch Ken Viaduct and at Bordeaux. In the bridge at Nantes there is a load of 152 cwt. to the square foot on sand, but some settlement has taken place. Under the cylindrical piers of the Szegedin Bridge in Hungary, the soil, consisting of clay intermixed with fine sand, bears a load of 133 cwt. on the square foot, but it was deemed expedient to increase its supporting power by driving some piles in the interior of the cylinders, and also to protect the cylinders by sheeting outside. Cylinders, moreover, sunk to a considerable depth in the ground, possess a lateral adherence, as is evident from the weights required for sinking them, which adds greatly to the stability of the foundations. Taking into account this auxiliary support, the loads of 159 and 117 cwt. on the square foot, at the bottom of the cylinders of the Charing Cross and Cannon Street Bridges respectively, are not excessive. On a rocky ground the Roquefavour Aqueduct exerts a pressure of 267 cwt. to the square foot.

Bridge foundations may be classed as ordinary foundations, on land or protected from any considerable rush of water; and hydraulic foundations in rivers or in the sea. When the ground consists of rock, hard marl, stiff clay, or fine sand, the foundations can be laid at once on the natural surface, or with slight excavations, and with horizontal steps where the ground slopes. At the edge of steep descents, with dipping strata, it is necessary to find layers that will not slip, or if there is such a tendency, to strengthen the layers of rock by a wall, especially when it is liable to undergo decomposition by exposure to the air, or to use iron bolts uniting the layers of rock. On ground having only a superficial hard stratum resting upon a soft subsoil, buildings have sometimes been erected by merely increasing the bearing surface, and lightening the superstructure as much as possible; but generally it is advisable to place the foundations below all the soft soil. On an uneven surface of rock a layer of concrete spread all over affords a level foundation. Sometimes large buildings have been securely built on quicksand, of too great thickness to be excavated, by the aid of excellent hydraulic mortar, and by excavating separately the bed of each bottom stone. Such a building will be stable if its pressure on the foundations is uniform throughout, and if it is placed sufficiently deep to counterbalance the tendency of the sand to flow back into the foundations.

One means of reaching a solid foundation, without removing the upper layer of soft soil, is by piling, but piles are liable to decay in many soils. Sometimes columns of masonry support the superstructure, but being placed farther apart than piles, it is necessary to connect them with arches at the surface. Piers, however, of viaducts supporting a heavy load must be carried down in one mass to the solid ground, as in the case of the viaduct of Otzaurte, on the Rio Salera, in Spain, where it was necessary to get through 65 ft. of silty clay to lay the foundations of a pier 31 ft. long by 13 ft. wide. In order to avoid getting out so large an excavation in one piece, a well, Fig. 495, was dug 4 ft. wide, and extending across the whole width, 13 ft., of the pier, so as to divide it into two equal portions. A chamber 9 ft. 10 in. high, was then driven at the bottom, like a heading, as far as the limits of one half of the foundations of the pier, and built up with masonry. The other half was similarly dealt with, and the excavation and masonry was carried up in successive lifts of 9 ft. 10 in. The central well served as means of access for pumping water out, for the removal of earthwork, and the supply of materials.

495.



To avoid the difficulty and expense of timbering deep foundations, a lining of masonry is sometimes sunk, by gradually excavating the ground underneath, and weighting the masonry cylinder, which is eventually filled in with rubble stone, concrete, or masonry, and serves as a pier.

In India a similar system has been followed for centuries for sinking wells, which we describe at length at page 200.

When the stratum of soft soil is too thick for the foundations to be placed below it, the soil must be consolidated; or the area of the foundations must be sufficiently extended to enable the ground to support the load. The ground may be consolidated by wooden piles; but in soils where they are liable to decay, pillars of sand, or mortar, or concrete, rammed into holes previously bored, may be used. Artificial foundations are also formed by placing on the soft ground, either a timber framework, surrounded occasionally by sheeting, a mass of stone rubble, a layer of concrete, or a thick layer of fine sand, spread in layers 8 to 10 in. thick, which, owing to its semi-fluidity, equalizes the pressure.

When the foundation is not homogeneous it is necessary to provide against unequal settlement, either by increasing the bearing surface where the ground is soft, or by carrying an arch over the worst portions.

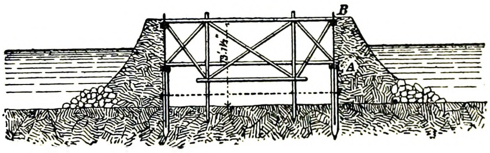
Bridge foundations in water are laid upon the natural surface where it is rocky, also on beds of gravel, sand, or stiff clay, secured against scour by aprons, sheeting, rubble stones, or other means of protection. When the foundations are to be pumped dry, dams are resorted to if the depth of water does not exceed 10 ft., and especially where the water is less deep and rapid, and the bank forms one side of the dam. The dam can be made of clay, or even earth free from stones and roots, with slopes of 1 to 1, the width of the top being about equal to the depth of water, when the depth does not exceed 3 ft. in a current or 10 ft. in still water. The leakage of a dam and the danger of breaches increases rapidly in proportion to the head of water.

Concrete makes a solid dam, but it is expensive to construct and difficult to remove.

A cofferdam with a double row of piles takes up less space, and is less liable to be worn away or breached than an earthwork dam. The width of a cofferdam is often as great as the head of water; but if strutted inside, so that the clay acts as a water-tight lining, the width need not exceed from 4 to 6 ft. In a cofferdam of concrete at Marseilles, the widths were calculated at 0·45 of the total height; the maximum width had thus attained 20 ft.

In building the viaduct at Lorient, on a foundation dry at low water, a single row of strutted piles, ¾ ft. apart, planked from top to bottom on both sides, was used, and the space between the planking, 10 in. wide, was filled with silt, pressed down. When the filling is so much reduced in thickness the planks are carefully joined, and the clay mixed with moss or tow, or sometimes with fine gravel or pounded chalk. As water leaks through joints and connections, the ties are placed as high up as possible, and the bottom is scooped out or cleaned before the clay is put in. When the sides of the part to be enclosed are sufficiently close, they may be effectually supported by a series of stays, as was done in making the dam for the construction of the apron of the Melun dam, Fig. 496, where struts were put in at intervals of 16½ ft.

496.

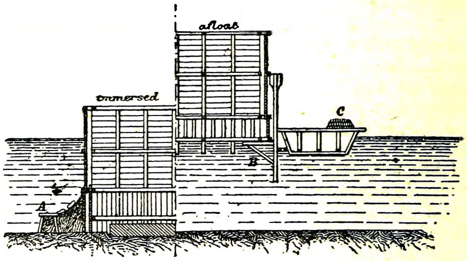


If large springs burst out in an excavation, they must either be stopped up with clay or cement, or be confined within a wooden, brick, or iron pipe, in which the water rises until the pressure is equalized, and then is stopped up as soon as the masonry is sufficiently advanced and thoroughly set. If, however, there is a general leakage over the whole bottom, it must be stopped by a layer of concrete, incorporated with the foundation courses.

Hollow timber frames without a bottom, and made water-tight at the bottom after being lowered by concrete or clay, are suitable in water from 6 to 20 ft. deep on rocky beds, or where there is only a slight layer of silt. This method was resorted to by Beaudemoulin, between 1857 and 1861, at the St. Michael, Solferino, Change, and Louis Philippe bridges at Paris. The timber frame at the St. Michael's Bridge was 15 ft. 9 in. high, 125 ft. long, and 19 ft. 8 in. wide at the base, with a batter of 1 in 5; the uprights were 6 in. square, and 6½ ft. apart; the framework was of oak and the planks of deal, 9 in. by 3 in., the spaces between them being covered by small laths nailed on to the planks. Fourteen crabs placed on four boats supported the framing, and let it down as it was built up; this was weighted with stones to sink it on the foundations prepared by dredging, and the planks were then slipped between the wallings, and beaten down lightly.

At the Point du Jour the caissons were 131 ft. long and from 26 to 33 ft. wide, and from 21 to 26 ft. high. The long sides were put together flat on the ground, and were lifted up to allow of the short sides being fixed to them. A few hours sufficed for depositing the caisson in its place. Picard, in reconstructing the Bezons Bridge after the Franco-German war of 1870, used caissons in two portions, as the lower portion had to remain, whilst the upper portion was only needed for a time. Some nails and straps fastened the two portions together. A layer of clay was placed under the rubble toe outside, to prevent leakage between the concrete and the planks This expedient was first adopted by Desnoyers, in order to pump dry foundation carried down into clay, so as to build masonry walls on the bottom without using concrete. At the Aulne viaduct, in Brittany, Desnoyers and Arnoux made a caisson, Fig. 497, 75 ft. 6 in. × 34 ft. 9 in., and nearly 23 ft. high, and, with the exception of the bottom portion, caulked beforehand. When it was deposited the bottom planks were slid down between the lower set of wallings, and a toe of puddled clay, A, protected from the rush of the current by canvas, was put round the bottom outside. When the caisson, put together on a stage supported on eight boats C, was ready for depositing, it was lowered till the projecting pieces B touched the ground, and by cutting the beams fastening these projections to the boats, the boats were set free. As the tide rose the caisson floated, and the boats were attached to its upper part, which by lightening lifted it sufficiently for the projecting pieces to be taken off. The depositing was completed by allowing the caisson, weighted with rails, to sink on the dredged bottom, as the tide fell. Thus, by the help of water alone, a mass weighing 74 tons was safely and accurately deposited. Large caissons have also been employed, with an interior dam of concrete forming a permanent part of the foundation, instead of an external toe of clay; and caissons have also been made water-tight by a dam of clay inside, which necessitates a somewhat larger caisson, but admits of the removal of the timber.

497.



When a limit to the space occupied is immaterial, a sort of double-cased cribwork dam is frequently adopted. Although iron caissons are generally used for penetrating some distance into the soil, there are instances of iron caissons being merely deposited upon the natural bed.

The methods employed for laying foundations in the water, either on the natural surface or after a slight amount of dredging, have next to be considered.

A rubble mound foundation is sometimes employed. Such a method, however, is little suitable for bridge-work, where a slight settlement would be injurious.

Another method consists in sinking a framing, not made water-tight, inside which concrete is run, and the framing remains as a protection for the concrete, and is surrounded by a toe of rubble. If the framing is of some depth, iron tie-rods are put in by divers after the bottom has been dredged, to enable the framing to support the pressure of the concrete. When piles can be driven the framing is fixed to them. The piles, 5 to 8 ft. apart, have a double row of walings fixed to them, between which close planking is driven, from 10 to 14 in. wide and from 3 to 5 in. thick; and sometimes, when the scour of a sandy subsoil has to be prevented, the planks are grooved and tongued, or have covering pieces put on by divers, or are driven in close panels.

In permeable soils, foundations of concrete enclosed in frames are frequently employed, but in silty and water-tight soils, foundations in excavations pumped dry are preferable.

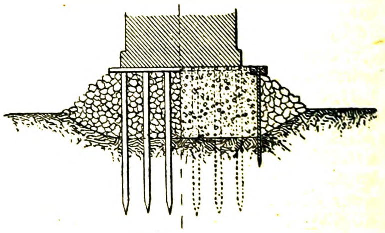
The bed of the Rhone at Tarascon, consisting of sand and gravel, in which piles are difficult to drive is subject to scour in floods to a depth of 46 ft. Foundations, however, were laid there at considerable expense, by frames with double linings, 10 ft. apart, in which large blocks were placed with unhewn stones on them; the ground was then dredged inside the frames to 28 ft. below low-water level, and 260 cubic yds. of concrete deposited in twenty-four hours.

Lastly, concrete can be deposited *in situ* for bridge foundations; and though concrete blocks are only used in sea-works, bags of concrete are sometimes employed, instead of rubble stones, for forming the base of piers or for preventing scour.

Piles are used where a considerable thickness of soft ground overlies a firm stratum, when the upper layer has sufficient consistency to afford a lateral support to the piles, otherwise masonry piers must be adopted.

The piles are usually placed 2¼ to 5 ft. apart, centre to centre. A timber grating can be fastened to the top of the piles, or a layer of concrete is deposited, or both grating and concrete, as the grating distributes the load and strengthens the piles. Planking is sometimes put on the framing which distributes the pressure, as at London Bridge, but it is considered objectionable, as it prevents any connection between the superstructure and the concrete, and increases the chance of sliding. The space between the piles, from the river bed to low water, is sometimes filled with rubble stones and sometimes with concrete, as in Fig. 498, which is less liable to disturbance. When the ground is very soft a filling of clay has been preferred on account of its being lighter than concrete.

498.

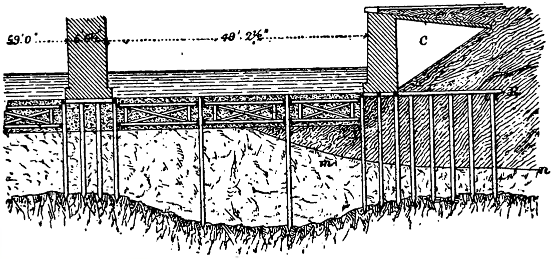


A mixed system of piling and water-tight caissons, of rubble filling and concrete, was adopted at the Vernon Bridge. After the piles had been driven, the spaces between them were filled up to half the depth of water with rubble stones; a caisson 10 ft. high was then placed on the top, and a bottom layer of concrete deposited in it. In a month's time, the interior of the caisson was pumped dry, the heads of the piles cut off, and the filling with cement concrete completed to low-water level. The caisson was cut off to the level of the grating as soon as the pier was above water.

The load that a pile driven home and secured from lateral flexion can bear, may be estimated at from $\frac{1}{10}$ to $\frac{1}{8}$ of the crushing load, which varies between 5700 and 8500 lb. on the sq. in. Thus taking a fair load of 710 lb. on the sq. in., a small pile 7 in. in diameter will bear about 12 tons, a pile 18 in. diameter about 80 tons, and a pile to bear the load of 25 tons used as a unit by Perronet should be about 10 in. in diameter.

In order to prevent the danger of overturning in silty ground, the ground is sometimes first compressed by loading it with an embankment, which is cut away after a few months at those places where foundations are to be built. At the Oust Bridge it was even necessary to connect the piers and abutments by a wooden apron, which, for additional security, was surrounded by concrete, Fig. 499. The abutment C was made hollow to lighten it, and the embankment R had compressed the silty ground *m n*. At the bridge of Bouchemaine, near Angers, the bending of piles, which traversed about 20 ft. of silt, has been stopped by surrounding them with great masses of rubble stones.

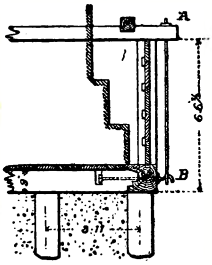
499.



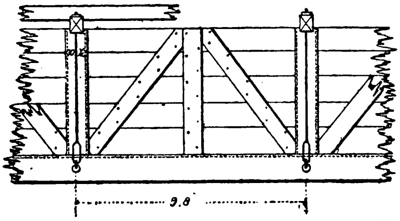
Occasionally foundations on piles have failed or suffered great sets or lateral displacements. See article on Pile Driver, at p. 2616 of this Dictionary.

Floating caissons require a bottom carefully levelled on which to be lowered; but usually this kind of caisson is deposited on piles cut off to one level. These caissons have oak bottoms and movable sides of fir, and enable the masonry piers built inside to be lowered on piles previously driven. The oak bottom serves as a platform for the pier, and the movable sides can be used again for other caissons. At Ivry, with only two sets of movable sides the four caissons were put in place in one month. The bottom, which consists of a single or double platform, has timbers projecting underneath, which fit on to the row of piles. The movable sides are sometimes made in panels, which fit into grooves both in the bottom framing and in upright posts, placed about 10 ft. apart, which are tenoned at the bottom and kept in place at the top, by transoms going across the caisson. The different parts of the sides are pressed together by the bolt A B, Figs. 500, 501. In other instances the sides butt against the vertical sides of the bottom, against which they are pressed by keyed bolts D, Figs. 502, 503, placed at intervals of 5 ft. The caisson is kept near the shore whilst the first courses of masonry are being built in it; it is then on a favourable opportunity floated over the site of the pier prepared to receive it, and is gradually sunk by letting in water.

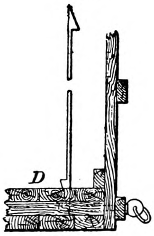
500.

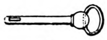


501.



502.





503.

Screw piles have been principally used in England and in the United States; they will penetrate most soils except hard rock, and can get a short way into compact marl, through loose pebble and stones.

Piles with discs differ little from screw piles except in the method of sinking them. This operation is performed by sending a jet of water down a wrought-iron tube inside the cast-iron pile, which washes away the silty sand from underneath the disc and causes the pile to descend. Wooden piles, with a cast-iron shoe carrying a disc, might easily be sunk in the same manner, the water-pipe being carried eccentrically through the disc.

Hollow wrought-iron piles have also been forced down by blows of a monkey, in silty and sandy ground interspersed with boulders, to a depth of about 60 ft.; the thickness of the piles being about $\frac{1}{9}$ in., and the diameter 19$\frac{2}{3}$ in.

Large masonry piers carried through thick layers of soft ground to a solid bed may be constructed by various methods, and constitute the best kind of foundation in such a situation.

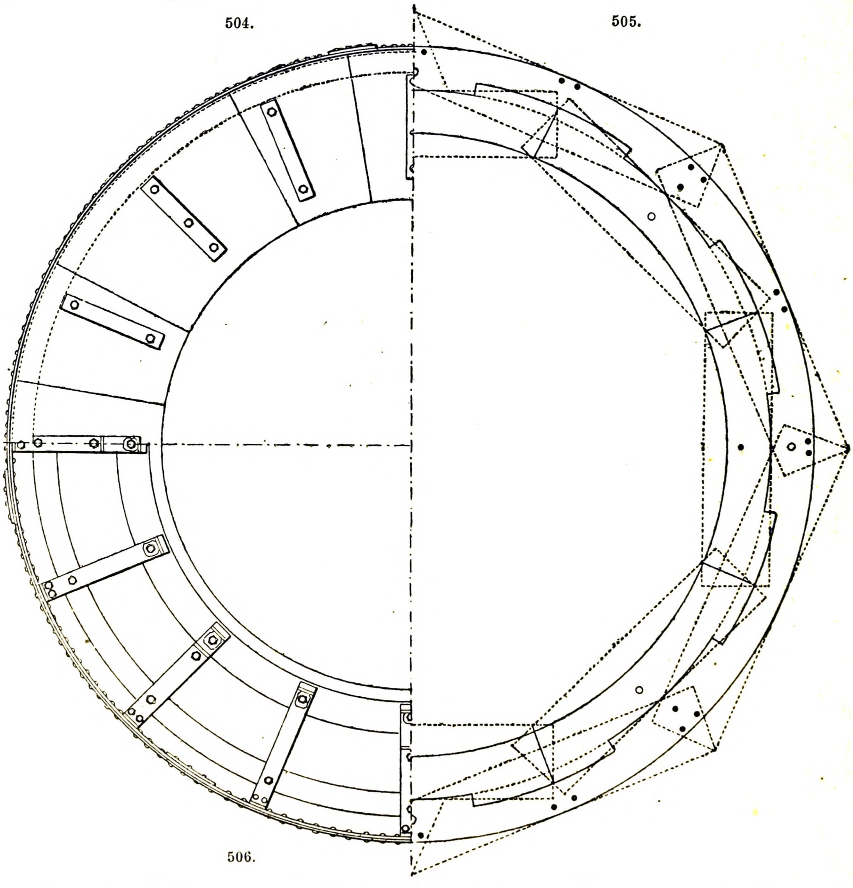
The method of cased wells is suitable, where the silt is sufficiently compact and water-tight to admit of pumping the well dry, and where the depth of water is small, and can be easily kept out by a cofferdam, or a caisson without a bottom. The well is sunk by the ordinary method of sinking wells or driving headings in silty ground. When the pier is so wide as to render strutting difficult, an outer ring can be first lowered, which serves afterwards as a casing for excavating the inner portion. When permeable gravel or very liquid silt has to be traversed, it is necessary to resort to tubular foundations.

Cylindrical foundations are sunk with or without the aid of compressed air according to circumstances. These foundations possess two great advantages of being capable of being sunk to a considerable depth, and of presenting the least obstruction to the current.

In a clay soil the cylinder acts as a movable cofferdam, which is sunk by being weighted, and enables the foundations inside to be built up easily and cheaply. Iron cylinders are preferred in certain cases to cylinders of brick, masonry, or concrete, on account of the ease with which they are lowered in deep water on to the river bed; in spite of the disadvantages attaching to them of high price, of the considerable weights required for sinking them, and lastly of being only cases for the actual piers.

In India, where this method is largely employed, the linings are made in radiating courses of bricks or stones; the first length, from 5 to 10 ft. high, being put on a circular wooden framework placed on the surface of the ground. Very fine sand is used for filling the joints, except for the two or three top courses, which are laid in mortar, and the whole construction is tightly bound together. It is then gradually sunk by a man inside undermining it, and another length is placed on the top. As these operations are generally conducted in the silty or sandy beds of rivers which become dry in summer, there is no running water to contend with, but water percolates into the excavation, and then the natives use a jham, a peculiar native tool, by which they remove the earth from under water. Although the external diameter of the wells has been sometimes limited to 5 ft., the advantage of larger dimensions in securing a vertical descent has been always recognized. At the Western Jumna Canal rectangular linings were adopted with advantage. At the Solani Aqueduct, hollow cubes with sides 20 ft. long, and at Dunowri oblong or square linings, 30 ft. long and 20 ft. deep, and subdivided into three or four compartments, were used.

504. 505.



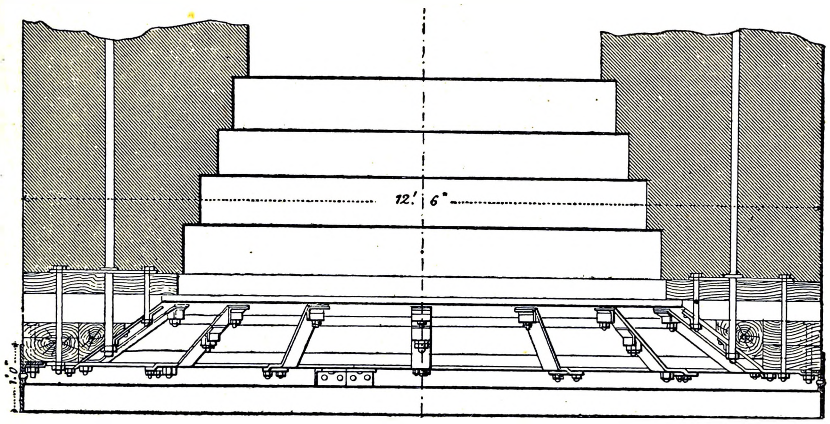
506.

Imric Bell added a pole to the jham used by natives to save the trouble of diving, but even with this addition the process was slow. The foundations of the Poiney Viaduct, on the Madras railway, were put in by this method. In more recent works the curb is made of iron, or of iron and timber, and angular. The excavation is now usually made by excavators or dredges, and the cylinder finally filled with concrete.

The curbs for the Alexandra Bridge, on the Punjaub Northern Railway, were of hard timber, built up of wedge-shaped segments below and additional flat covering pieces above, all breaking joint, and forming a ring of 2 ft. broad and 2 ft. deep. The component parts were securely fastened together with $\frac{3}{4}$-in. bolts, and the bottom of the wedge was armed with a cutter plate of $\frac{1}{2}$-inch iron 12 in. deep, riveted to a ring of 3-in. angle iron, which was again bolted to the timber, the wedge pieces or segments resting thereon. The outside diameter of the curb was 12 ft. 6 in., corresponding to the size of the well. The steining of the latter was 3 ft. 3 in. thick, reducing the internal diameter to 6 ft.; therefore the brickwork was gradually corbelled inwards from the curb until the full thickness was obtained. Eight tie-rods placed at equal distances around the curb were continuous throughout the steining.

Fig. 504 is a quarter plan at top, and Fig. 507 a section of a combined iron and timber curb such as the above. Fig. 506 a quarter plan of the bottom. Fig. 505 a half plan of the upper side of the lower segments of timber. The scantlings out of which the segments are cut are shown by dotted lines, the position of the timber tie-bolts by the large dots, and of the vertical tie-bolts by circles. The inner timbers have butt joints, the outer timbers overlap.

507.



The wells were built in five lengths of 14 ft. each. At the top of each length, a ring of bar iron was laid in the brickwork, the tie-rods passing through it and being screwed down tight by a nut 6 in. in length. The next length of tie-rod was screwed into the upper half of this nut or coupling, and so on. Thus each length of well was a compact cylinder in itself, capable of being pulled from side to side while sinking without injury to the brickwork. The curbs weighed 3 tons each.

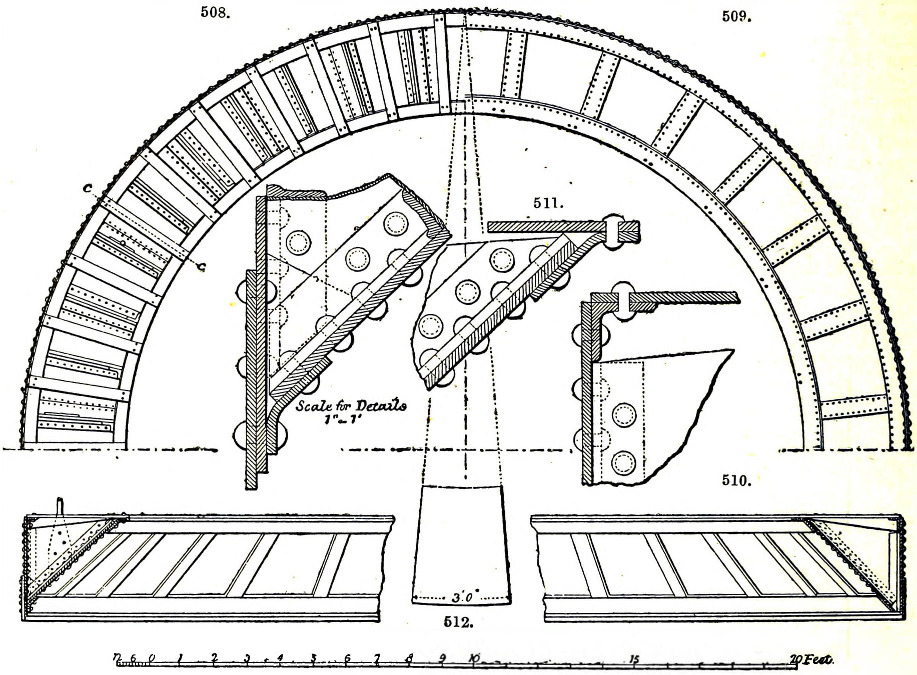
The practice at the Ravi Bridge, was to build a cylinder of brick 12 ft. 6 in. in diameter, and of the same height, and sink it from 10 to 12 ft. Another length of 12 ft. 6 in., total 25 ft., was then added, and sunk about 20 ft.; next a length of 25 ft. of cylinder, total 50 ft., was built and sunk, as far as possible without weighting, usually 35 to 40 ft. Finally a length of 20 ft. was built, completing the 70 ft. of cylinder which was sunk without further weighting, sometimes to 60 ft., when a load of 150 tons of rails commonly sufficed to complete the sinking to 70 ft. The greatest load required for any well was 250 tons. At the commencement of the works the curbs were pitched 6 in. apart, and much difficulty was experienced from the cylinders drawing together. This was effectually remedied by pitching the remainder 2 ft. apart. When cylinders have to be sunk to great depths, they should probably not be nearer together than $\frac{1}{6}$ of their diameter, 2 ft. being the minimum distance. The average progress with the large cylinders at Ravi, was 2 ft. a day of sinking, or 8 in. a day of actual work, including building and loading.

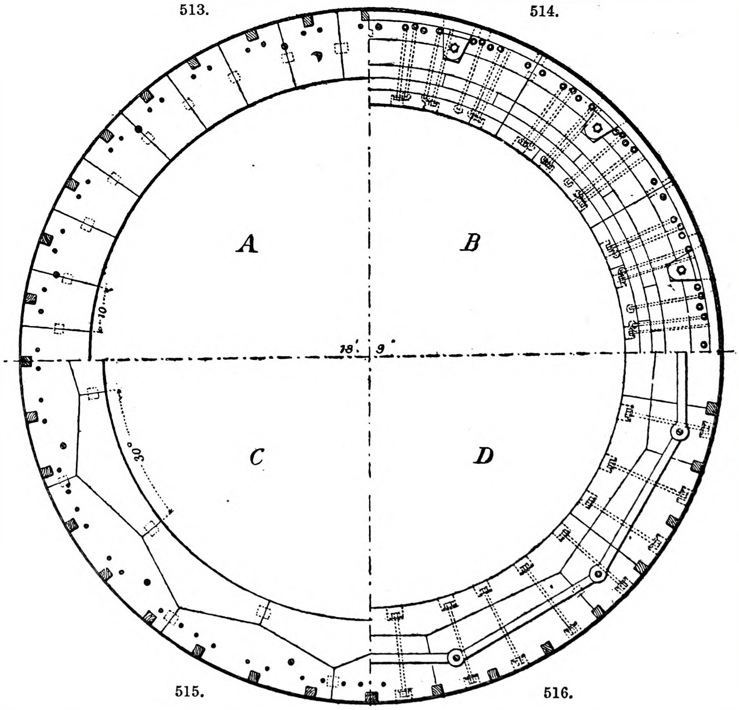
Fig. 508 is a quarter bottom, Fig. 509 a quarter top plan, Fig. 510 a vertical section, Fig. 511 enlarged sections on the line C C of the gusset, tie-bars, and their connections, of the wrought-iron curbs as used at the Chumbul Bridge, Sindia State Railway; Fig. 512 being the development of the conical plate.

Figs. 513 to 516 are quarter plans on the radial course A, bottom B, third course C, and top D respectively, Fig. 517 half section, and Fig. 518 half elevation, of the combined iron and timber curbs for 18 ft. 9 in. wells, employed for the foundations at the Sutlej Bridge, on the Indus Valley Railway.

At the Glasgow Bridge the lining was of cast-iron rings, being easier to lower in mid-stream; but for the quays and docks on the Clyde, linings of concrete and brickwork were adopted for the sake of economy. Milroy considers that with concrete, which can be moulded to an edge at the bottom, all metal additions may be omitted where only silt and sand have to be traversed, and that the bottom ring should be of iron for penetrating harder soils. In the Clyde extension works, the wells were filled up with concrete, and a double row of cylinders 9 ft. diameter adopted in preference to a single row of 12 ft. It would be possible in this arrangement to take out the sand between the adjacent cylinders, and form them into a solid mass by filling up these interstices with concrete.

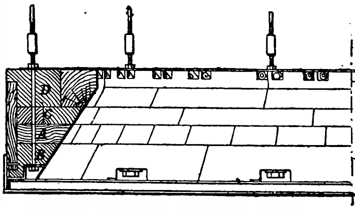
The foundations for the piers of the Kansas City Bridge, U.S., were sunk by Chanute and Morrison, who used open caissons carried down to the bed rock, or to a hard gravel into which piles were driven, and filled with béton for most of the piers. The work was one of difficulty, as the River Missouri at the point crossed has great depth and a rapid current. Pier No. 4 was therefore founded by the arrangement Figs. 519, 520, which is an adaptation of the Indian well


508. 509. 510. 511. 512.
C
C
Scale for Details 1" = 1'
3'0"
12 6 0 1 2 3 4 5 6 7 8 9 10 15 20 Feet.

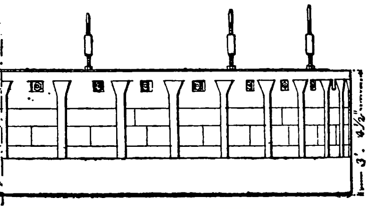

513. 514. 515. 516.
A
B
C
D
10'
18' 9"
30'

method. The left side of Fig. 519 is a section, and the right an exterior view, of one half; Fig. 520 being a cross section of the works. The caisson was 70 ft. long, 20 ft. 6 in. wide, and 11 ft. in height; the sides were of square timber, the main sills of oak, the seven succeeding courses of pine placed on edge, the two upper timbers of oak, and a triangular piece of oak was placed below the main sill. The courses were pinned together and bolted to uprights, the outside being covered with two courses of 3 in. oak planks planed. Within this outer wall was placed an inner one framed of oak timbers, inclined inwards, and stayed by iron bolts binding them to the outer walls. Three V-shaped cross walls divided the interior of the caisson into four chambers, the cutting edges of both main and cross walls being protected by a covering of $\frac{3}{16}$ in. boiler plate. The whole was caulked, and the interior coated with roofing pitch. The caisson was provided with a false bottom, placed below the cutting edge; this was removed as soon as the caisson was floated into position. Four large endless chain dredges served for excavating. After the caisson was brought into position, the openings into the lower chambers were surmounted by timber boxes, this being continued from time to time as the work progressed. When the hollow walls of the caisson had been filled with béton, a second section was built above it, this being an open frame structure covered with planks and also filled with béton, the entire structure thus becoming purely the covering of an artificial monolith, carrying the masonry of the pier above. The plan adopted at the Kansas Bridge admits of wide application, and by slight modification can be combined with the pneumatic method, in such a way as to allow of extraordinary obstacles being removed by men, whilst the entire sand excavation is made by machinery. Where facilities exist, caissons should preferably be made of iron.

517.



518.



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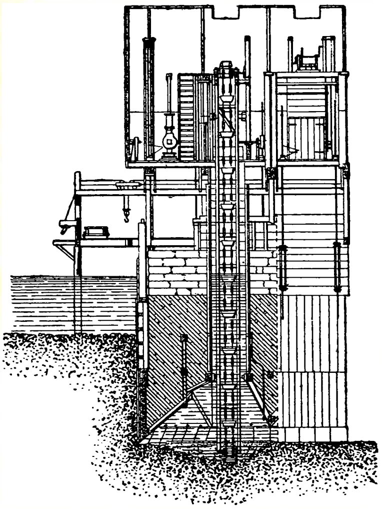
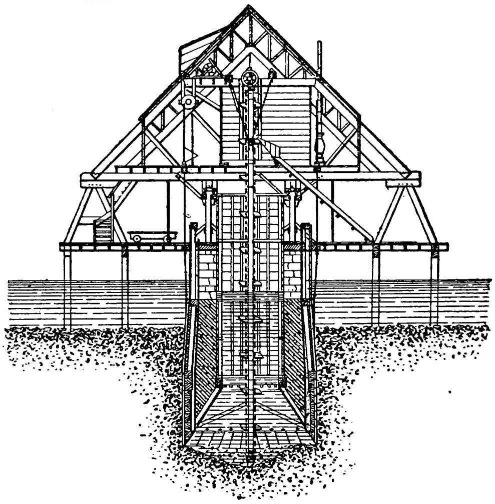


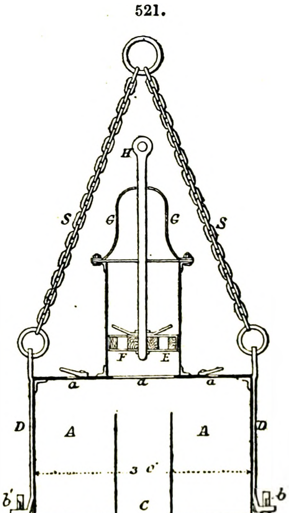
520.



The extension of the system of sinking cylinders by dredging must depend chiefly on improvements in the dredging machinery, of which the successive steps in advance already attained may be noticed.

The jham in India was superseded by Kennard's sand-pump, Fig. 521. A is a wrought-iron cylinder, having a pump E riveted to it at the top by an angle iron. In this cylinder is a piston F fitting loosely, having a play of about $\frac{1}{8}$ in. all round. It is made of lead, and is pierced with small holes, to allow of the escape of the water as it descends, and on the top it has a flap of leather or indiarubber. It is protected by plates of iron $\frac{1}{8}$-in. thick, at top and bottom, and on the sides by an iron ring $\frac{1}{4}$ in. thick. The piston rod passes through a

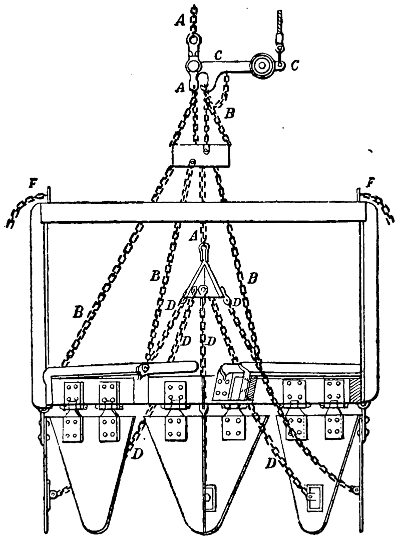
521.



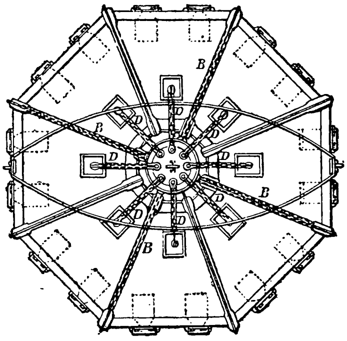
guide G, and terminates in an eye H at the upper end, to which a chain is attached to work it. The bottom B of the cylinder is movable, and an upright suction pipe C is riveted to it at the centre. This pipe projects outwards for a distance equal to its own diameter, and inwardly nearly to the top of the cylinder. The movable bottom is supported by cramps *b*, turning in the four movable stiffening pieces D, riveted to the sides of the cylinder, the cramps being tightened by cottars *b′*. At the top are eyes for lifting and lowering the pump by slings S. The holes *a*, fitted with the hinged flaps, are to allow the escape of water as the sand fills the cylinder, and a large hole cut out of the centre allows the pump to work. With this machine a well, 12½ ft. in diameter, was sunk in the Jumna 8 or 10 in. an hour by fourteen workmen. As the Kennard pump was not able to work in the compact clays and conglomerate met with in rebuilding the bridges over the Beas and the Sutledj, Bull's dredger was adopted, which consists of a semi-cylindrical case with jaws opening in two quadrants, like the American dredger of Morris and Cummings; it has been observed, however, that when it met a hard stratum, a descent of only 2 ft. 10 in. was accomplished in three months, whereas in the upper layer the progress was much more rapid than with the sand-pump.

Next came Milroy's excavator, Figs. 522, 523, which consists of a frame of iron, with an outside rim 9 in. in height, to which radiate T irons from a ring in the centre. To the bottom are hinged eight heavy spades, which, when drawn in, fit closely into each other, with their points pressing against the ring in the centre of the frame. The hinges are constructed so as to prevent turning back beyond the perpendicular when the spades open, or when forced into the ground. The movements are effected by two sets of chains attached to a hoisting chain A, Fig. 522, this passing over a pulley aloft, on to the barrel of a double-acting 12 H.P. engine. The first set of chains, all of equal length, are fastened at one end to the rim. At the other end they unite into a single chain, which is connected to a clutch C. These are for lowering, and when the tool hangs by them the spades fall open from their own weight. The second set of chains D are eight in number, of equal length, and fastened at one end to the inside of a spade, and at the other to the end of the main chain.

522.



523.



Before lowering the excavator, the chains B are hooked up, to the extent of their length of single chain, on the monkey-hook C. As soon as the spades are felt to be in the ground, the clutch C is disengaged by means of a rope, and the chains slackened. When this takes place, and the engine begins to pull in the main chain, the chains D, being now shorter than the other set, are brought into play, drag the spades through the ground, and raise the whole to the landing-stage. A lorry is then pushed in underneath. The chains B are hooked up, the machine is raised a little, when the spades fall open the material is emptied into the lorry. In order to force the spades into the ground, two timber guides are lowered down on opposite sides inside the cylinder, and are maintained at the proper distance apart, by being fastened at their lower ends to a strong iron hoop, and at the upper to the cylinder itself. As the depth increases, additional timbers and hoops are added. These guides have no connection with the cylinder except at the top, and can be easily removed. Each guide is composed of two timbers 6 in. by 4 in. fastened together, between which is fixed at either end a pulley. A separate chain F fastened to the top of an upright T iron passes down the cylinder, under the lower and over the upper pulley of a guide, and is wound round the large axle of a capstan on the landing-stage. When this chain is tightened, it tends to force the spades into the ground, and to keep the machine down while they are being drawn in.

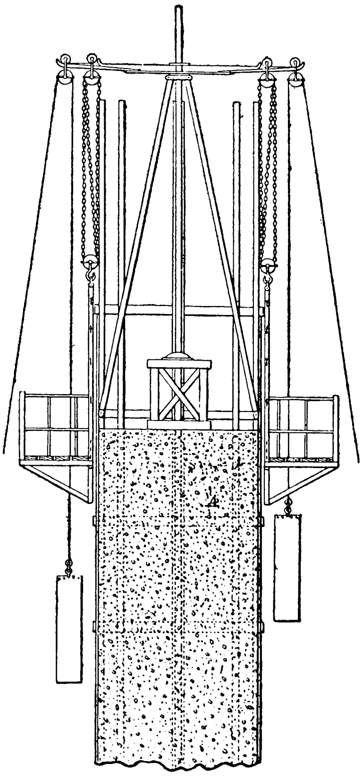
At the Glasgow Bridge, one of the works where Milroy's excavator has been employed, the progress was, on the average, 11½ ft. a day, and the maximum 20 ft. Another machine to effect the same purpose is the screw-pan, used at the Loch Ken Viaduct, a conical perforated vessel, the diameter at the top being 2 ft., and furnished at the bottom with a screw which enters the ground when turned. The sand and mud entering the vessel are retained by little leather valves when the instrument is lifted. It works well in silt and clay; in harder soils a smaller vessel is needed.

The boring head used by Leslie, at the Gorai Bridge, consisted of a revolving plane with blades underneath, able to disintegrate hard clays and compact sand; this is worked inside the cylinder, and at the same time the excavated material is drawn up and removed from the cylinder by a siphon. To maintain an upward pressure in the siphon, the level of the water in the cylinder is always kept higher than in the river. The boring head made one revolution in about one minute and a half or 2 minutes, and excavated through clay and sandy silt at a rate of about 1 foot an hour. One advantage possessed by this system is that the rate of progress is independent of the depth. The side piers of the Gorai Bridge were sunk 124 ft. below the surface, and the river piers 98 ft. below low-water level. The mizers used in sinking wells for water supply, may also be applied to cylinder foundations under suitable conditions. The system of sinking by dredging is generally to be preferred to the compressed air system, except where numerous obstacles, such as boulders or embedded trees, are met with.

At the Kistna Viaduct in India, the piers are very irregular, varying in height from 34 ft. to 76 ft. 6 in.; each pier consists of two columns of wrought-iron cylinders 10 ft. diameter at the base, tapering to 7 ft. at the top. The vertical joints are formed internally of continuous T irons, riveted through to outside strips. The ends of each cylinder were planed to form horizontal butt joints, with strips inside and out. The cylinders were sunk to the underlying rock, and there held down by light bolts, each 2 ft. 1 in. long, by $1\frac{7}{8}$ in diameter. Holes drilled in the rock allowed these bolts to be let in head downwards, the screwed ends being attached to the cylinders, and the spaces filled in with Portland cement. The cylinders are filled in with cement concrete, and finished with stone caps, which form the bases for the bed girders, placed directly on the concrete.

Fig. 524 is a section of the arrangements made for erecting the cylinders, and filling in the concrete at Kistna. An annular platform surrounds the cylinder, suspended from radial arms which are carried by sheer legs. There are eight arms, one for each cylinder segment, and these are temporarily attached to the work; as this progresses the sheer legs are elevated by the central leg, carried upon the trestle resting on the concrete. The materials are raised to the staging by a lift and tackle, as in Fig. 524, where two iron plates are seen being thus raised. To prevent oscillation the staging is made fast to the cylinder after each shift.

524.



The friction between cylinders and the soil depends on the nature of the soil and the depth of sinking. For cast iron sliding through gravel, the co-efficient of friction is stated by Gaudard to be between 2 and 3 tons on the sq. yd. for small depths, and reaches 4 or 5 tons where the depth is between 20 and 30 ft. In certain adhesive soils it would be more. In sinking the brick and concrete cylinders in the silt of the Clyde, it was found to amount to about $3\frac{1}{2}$ tons a sq. yd.

In applying cylinder foundations, it is important to know the amount of frictional resistance in various strata and at different depths, in order to determine the load necessary to overcome this resistance, or to determine the depth to which a pier must be sunk to carry the load. According to A. Schmoll's experience, not only the nature of the soil but also the shape of the column influences the frictional resistance, the latter being smaller for cast-iron cylinders and rectangular caissons than for caissons of an oblong section. The details given in Table I. relate to the application of cast-iron cylinders, or of wrought-iron riveted caissons with vertical sides and with casings reaching above the water-level, for strata which form the bed of the Seine, Rhine, and Danube. In determining the frictional resistance, the following conditions must be observed;—The tube or caisson must be vertical. It must be free on all sides, neither attached to the guide chains nor resting upon its lower edge, but only kept in equilibrium by its weight, by the friction on its circumference, and by the internal air pressure.

To obtain these conditions, the total weight of the cylinder must be less than the frictional resistance plus the weight of the displaced water; or else sinking takes place without air being let off, and without the cutting edge being undermined. If these conditions be fulfilled, the air pressure shown by a gauge is recorded, the safety valve opened, and after the sinking motion of the caisson has begun, the air pressure is again observed and the valve rapidly closed. The beginning of the motion indicates that the effective air pressure, together with the friction at the circumference of the caisson, have become slightly smaller than the total weight of the cylinder.

As coefficients of friction relating to materials and surfaces which occur in cylinder foundations were unknown, A. Schmoll determined the following by direct experiment with a dynamometer.

TABLE I.—FRICTIONAL RESISTANCES OF PNEUMATIC FOUNDATIONS.

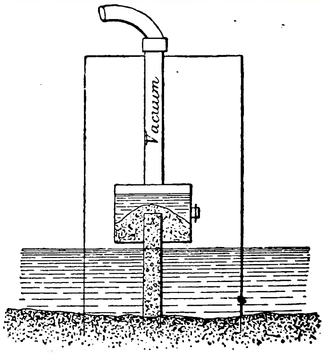
Description of Materials.	Coefficients of Friction.			
	Beginning of Motion.	During Motion.	Beginning of Motion.	During Motion.
	For Dry Materials.		For Wet Materials.	
Sheet iron without rivets on gravel mixed with sand	0·4015	0·4583	0·3348	0·4409
Sheet iron with rivets on gravel and sand	0·3965	0·4911	0·4677	0·5481
Cast iron unplaned „ „	0·3677	0·4668	0·3646	0·4963
Granite roughly worked „ „	0·4266	0·5368	0·4104	0·4800
Pine sawn „ „	0·4088	0·5109	0·4106	0·4985
Sheet iron without rivets on sand	0·5361	0·6313	0·3655	0·3247
„ with „ „	0·7269	0·8391	0·5156	0·4977
Cast iron unplaned „ „	0·5636	0·6063	0·4744	0·3796
Granite roughly worked „	0·6473	0·7000	0·4728	0·5291
Pine sawn „	0·6633	0·7340	0·5787	0·4793

Each figure is the average result of at least ten experiments. All materials drawn horizontally over the gravel or sand; the latter was bedded as solid as it is likely to be in its natural position. The riveted sheet iron contained twenty-five rivets on a surface of 4·22 sq. ft., the rivet heads were half round and of $\frac{13}{16}$ in. diameter.

The results of trials in sinking caissons as conducted by Schmoll show clearly that, in homogeneous strata, the resistance on each unit of frictional surface decreases with the increasing depth. From this it is to be concluded that the density and cohesion of these strata augment with increasing depth, and therefore the pressure upon the sides of the column becomes less than in the upper strata.

Passing on to the consideration of the pneumatic systems, the process of Dr. Potts was one of the first employed for sinking tubular foundations by the help of air. The cylinder in process of being sunk was connected with a vessel, Fig. 525, in which a vacuum was produced, and a communication between them being suddenly made, a shock was produced by the rush of air. The only advantage in the system was using air for applying a downward pressure on the cylinder, as dredging had still to be resorted to for removing the earth from the inside, and moreover, there was a considerable influx of the surrounding soil, and frequent divergences from the perpendicular. The difficulties of the Potts process increase with the size of the cylinder; and for sinking the cylinders, 10 ft. in diameter, of the Shannon Bridge, it was abandoned after an unsuccessful attempt.

525.



The vacuum barge system was employed in the Tay Bridge foundations by Reeves and Beattie. In this a series of pumps draw the sand through the centre of the cylinders with great rapidity and ease, the cylinders sinking by their own weight as the sand is removed. Upon a barge or lighter four cylindrical wrought-iron receivers are fixed, each about 5 ft. in diameter, to which are connected air pumps for exhausting, and the engines required to work them. The bottom of each receiver is fitted with a trap-door opening outwards over a hopper, and to the top is attached a flexible tube, which extends over the side and to the bottom of the hollow pier. As soon as the cylinder is sunk to the bed of the river, this barge is placed alongside it, and the flexible hose being directed by divers, inside the pier, the receivers are exhausted by the air pumps, and the sand and water rush up the cylinders to fill the vacuum. As soon as one receiver is full, the turn of a handle opens another, and the same process is repeated, the air pumps being kept constantly at work. A small air valve destroys the vacuum in the charged vessel, and the fall of the trap-door liberates the sand, which falls into the river again, but outside the pier instead of inside. By the adoption of four receivers constant working was secured, and the rate of sinking was rapid. The general dimensions of the sand pumps are; diameter of cylinder, 7 in.; stroke, 12 in.; diameter of air cylinder, 12 in.; stroke, 12 in.; steam, 50 lb. Each tank holds 60 cub. ft., and it takes from one to three minutes to fill one tank, according to the depth.

The method of compressed air for enabling operations to be conducted under water, introduced by Triger, is merely a modification of the diving bell.

Theoretically, when the lower edge of the cylinder has reached a depth of h ft., the pressure required for driving the water out of the excavations is $\frac{h}{3 \cdot 14}$ atmospheres; but frequently the intervention of the ground between the bottom of the river and the excavation, enables the work to be carried on at a less pressure. A considerably greater pressure would be required if water had to be forced from the excavation through the soil below the river bed; but this is avoided by placing a pipe inside to convey away the water, and Triger found that the lifting of the water was facilitated by the introduction of bubbles of air into the pipe at a certain height.

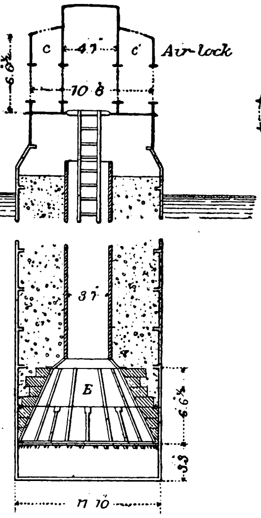
Pressures of two or even up to three atmospheres do not injure healthy and sober men, and suit best men of a lymphatic temperament, but prove injurious to men who are plethoric, or have heart disease. It is advisable to avoid working in hot weather more than four hours a day, or six weeks consecutively. From experiments on animals Bart has found that the accidents caused by a sudden removal of pressure, are due to the escape of the excess of gas absorbed by the blood, and the usual rule now is to allow one minute an atmosphere. The cylinders subjected to pressure, should be furnished with safety valves, pressure gauges, and alarm whistles, as explosions occasionally occur.

Iron rings from 6 ft. to 13 ft. in diameter are cast in one piece, and a caoutchouc washer introduced at the joints between the rings; cylinders of larger diameters are cast in segments, and cylinders of smaller diameter than 6 ft. are rarely used. The thickness is usually $1\frac{1}{8}$ in., increased to $1\frac{1}{2}$ or $1\frac{7}{8}$ in. where exposed to blows, in conical joining lengths, and in the bottom length.

When two cylinders have to be sunk close together, it is best to sink them alternately as they tend to come together when sunk at the same time. Sometimes where cylinders of small diameter have to be used, the excavations are extended beyond the cylinder at the bottom, and filled with concrete to give a greater bearing surface; another way of accomplishing the same object is to enlarge the lower rings of the cylinder, and put in a connecting conical length.

The cylinders at Bordeaux were forced down by strong beams of wrought iron, moved up or down by the pistons of four hydraulic presses, having 11 ft. length of stroke and exerting a pressure of 60 to 70 tons; at Argenteuil, where cylinders 12 ft. in diameter had to be sunk, the concreting inside was carried on during the sinking, leaving only a circular shaft in the centre 3 ft. 7 in. in diameter, lined with wooden framing, and enlarged at the bottom to a conical shape, by a sort of cage of inclined beams butting against the bottom of the shaft, Figs. 526, 527. The cylinders were sunk on the average 50 ft. below low-water level, through mud, sand, gravel, and clay, on to marl or limestone, and four screw-jacks of 20 tons power, supported the bottom ring by means of flat iron straps. After the sinking was completed, the chamber at the bottom was filled with cement concrete, poured around iron pipes placed near the sides, so as to maintain the air during the operation. When this layer of concrete was set the pipes were closed with cement, the normal pressure restored, and the shaft filled up with concrete. Concrete deposited under compressed air appears to set quicker, and to increase somewhat in strength, provided it is deposited in thin layers allowing the excess of water to escape, which may be effected by mixing very dry bricks with the concrete.

526



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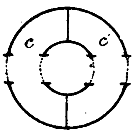

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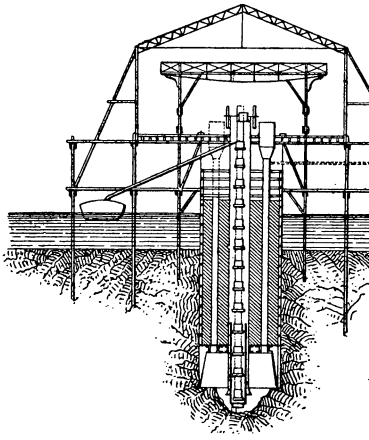

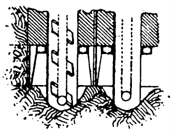

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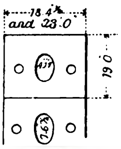


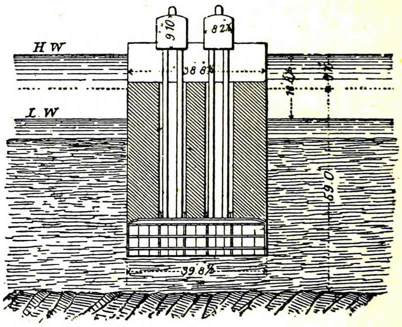
529.

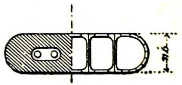
The foundations of the piers at the Kehl Bridge were accomplished by Fleur Saint Denis and Vuigner, by a combination of the principles of the compressed air process, the sinking of a pier by its own weight, the sinking by dredging, and the cofferdam system, Figs. 528 to 530. As the bed of the Rhine, at Kehl, consists of large masses of gravel, liable to be disturbed to 55 ft. below low-water level, the foundations were carried down about 70 ft. For the two centre piers the chamber of excavation was divided into three caissons, the length of each being 18 ft. 4 in., the width of the foundation. For the piers forming the abutments for the swing bridges there were four caissons, each 23 ft. long, the breadth of all the caissons being 19 ft. The plate iron forming the caissons was $\frac{3}{8}$ in. thick at the top, and $\frac{5}{16}$ in. thick at the sides, and strengthened by flanges and gussets.

The top was strengthened by double T beams for supporting the weight of the masonry above. There were three shafts to each caisson, two being air shafts 3¼ ft. in diameter, one being in use whilst the other was being lengthened or repaired; the other shaft in the centre was oval, open at the top and dipping into the water in the foundations at the bottom, so that the water could rise in it to the level of the river. In this shaft a vertical dredger with buckets was always working, and the labourers had only to dig, to regulate the work and remove any obstacles. The screw-jacks controlling the rate of descent had a power of 15 tons, and were in four pairs. The wooden framing serving as a cofferdam was erected above the chamber of excavation; it was useful at the commencement for getting below the water, but might subsequently have been dispensed with. It was also found that the caissons were sunk better in one division than in several divisions, and doors of communication were accordingly made through the double partitions. The iron linings to the air shafts were removed before the shaft was filled up. The shaft containing the dredger was at first made of iron, but afterwards of brick for the sake of economy. The sinking occupied sixty-eight days for one abutment, and thirty-two days for the other, giving a daily rate of 1 ft. 1 in. and 1 ft. 8½ in. respectively. The sinking of the caissons for the intermediate piers took twenty to thirty days, which gives a daily rate of 2 ft. 7½ in.

For large works, where the load on the foundations is considerable, carrying down the foundations to a hard bottom is much better than piling. The dredger used at Kehl cannot be regarded as universally applicable. Some soils are not suitable for dredging, and in other cases the small amount of excavation renders the addition of an extra shaft inexpedient. The chamber of excavation is almost invariably made of plate iron, but unlike those at Kehl, with the iron beams above the ceiling instead of below, so that the filling in could be accomplished more easily. The cutting edge is always strengthened by additional plates. At Lorient the thickness was $2\frac{3}{16}$ in., with several plates stepped back so as to form a sort of edge; the sides were about ½ in. thick at the bottom, and $\frac{5}{16}$ in. at the top, and the roof was curved a little to increase its strength. At Vichy the plates were about ¼ in. thick. At La Voulta, Hollandsch Diep, and Lucerne, a sort of masonry lining was placed against the iron plates, and kept in place by gusset plates, to afford greater rigidity against the pressure of the earth. At St. Maurice, wooden struts were put in at the base of the caisson, and also halfway up to support the sides. In consequence of these modifications, the caisson at Lucerne, 55¾ ft. by 13¾ ft., weighed only 28 tons; the caisson at St. Maurice, 32¾ ft. by 14½ ft., weighed 14 tons; whereas at Kehl, a caisson 23 ft. by 19 ft. weighed 34 tons, at Lorient, 39⅓ ft. by 11½ ft. weighed 27½ tons, and at Riga, 64⅓ ft. by 16 ft. weighed 45⅓ tons. The height of the chamber of excavation should be about 8 ft. 10 in. Frequently the cofferdam casing is of iron, which protects the newly built masonry from friction; and the upper portion of the casing can be removed. At Lorient there were two air locks, Figs. 531, 532, each connected with two shafts, in which balanced skips went up and down. On the top of the bottom caisson a casing of sheet iron, from $\frac{3}{16}$ to ⅛ in. thick, and weighing about 15 tons, was erected in successive rings.

531.





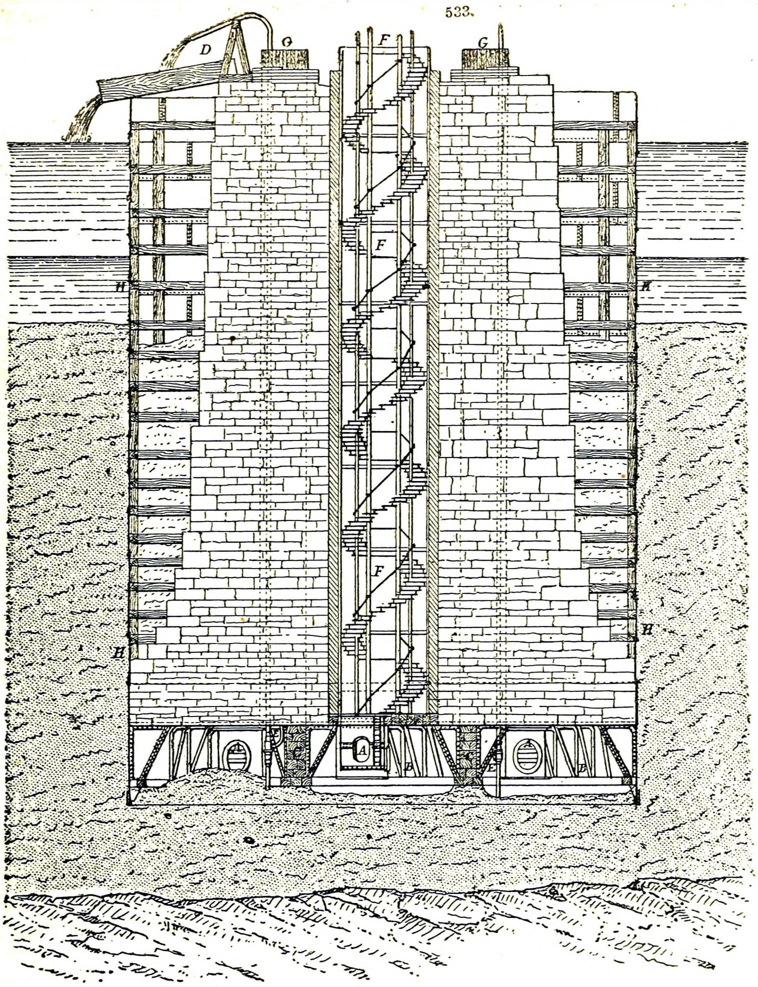
532.

The Americans have adopted the pneumatic system for some large works and introduced improvements. At the St. Louis Bridge the foundations were carried to a greater depth than had been previously attained; and at the East River Bridge, New York, compressed air was used in wooden caissons of large dimensions. The section, Fig. 533, shows the interior of the caisson in the St. Louis Bridge, with the main entrance shaft, the air-chamber, and working parts of one of the pumps employed for excavating the sand. A A are the air locks, B B the air chamber, C C the timber girders, D the discharge or sand pump, G G the side shafts, H the wrought-iron casing, I I timber bracing. The chamber is divided into three equal parts by timber beams C C, running in a direction at right angles to that of the iron girders above the roof. Inset pieces of plate iron are connected to these beams at intervals, to stiffen and support the roof. The bottom of the caisson projects a couple of feet below the timber beams and sills, so as to form a cutting edge.

The sand was forced up by a pressure of water amounting to 150 lb. the sq. in. One pump, having a bore of 3½ in., lifted 20 cub. yds. to a height of 125 ft. an hour. The masonry inside, Fig. 533, was built up as the caisson sank upon the air chamber. When the rock was reached, the shafts and the air chamber below were filled with concrete, and thus becoming one solid mass, constituted the real foundation or basis of the permanent structure. The caisson, H H, of plate iron ⅜ in. in thickness, was removed to be used again as required.

Fig. 534 represents the plant employed in laying the masonry and sinking the caisson. A A are the deck irons on the pontoons B B, F F hydraulic jacks for raising materials, K wire cable for supporting travelling purchases, M M shafts for starting and stopping the same, N N valve hydraulic jacks for raising and lowering materials, O air pumps and engines, Q hose for supplying air, S S screws for keeping the caisson level before reaching the sand, W W guide piles for caisson X, Z Z trusses for guide piles. It will be seen that a number of wrought-iron piles, about 3 ft. 6 in. diameter, are arranged round the caisson, and that these carry upon the framework they support a set of screws, each 25 ft. long, for maintaining the level of the caisson until the sand is reached. On the outside of the guide-piles are placed two pontoons, carrying double jibs, which

533.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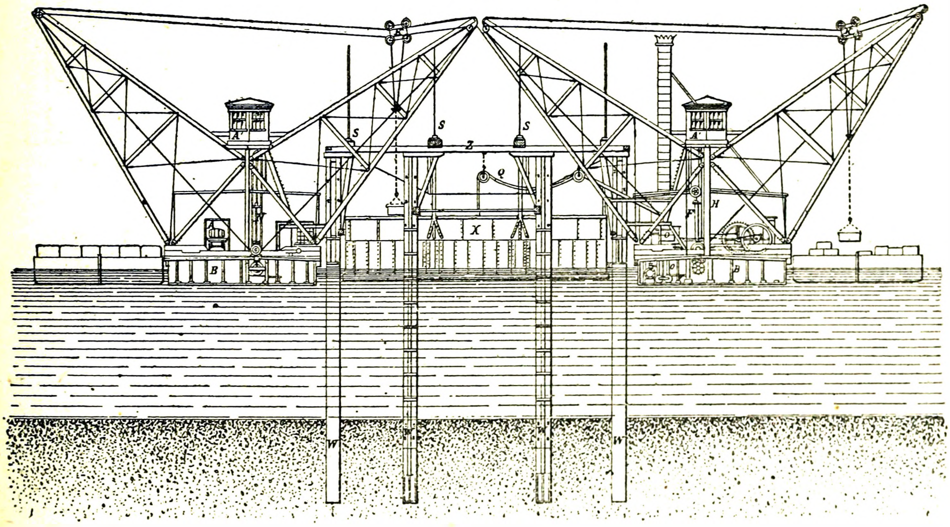
534.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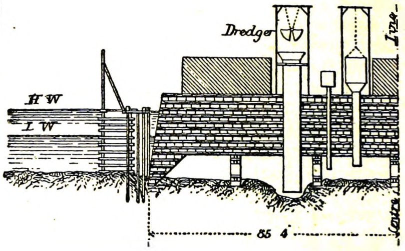
project on one side over the flats bringing the material, and on the other, meeting over the centre of the caisson. Between these are stretched wire cables, 2¼ in. in diameter, upon which run travelling purchases, that have a capacity of 11 tons, and a range of 100 ft. These were worked by hydraulic machinery in the usual manner.

The Brooklyn pier was to be carried 50 ft., and the New York pier 75 ft. below high water. To provide against unequal sinking, owing to the variable nature of the soil, consisting of stiff clay mixed with blocks of trap rock, Roebling decided to place the bottom of the piers upon a thick platform of timber, forming the roof of the working chamber, of which Fig. 535 is a half section. The sides were also made of wood, as being easier than iron to launch and deposit on the exact site. The roof consisted of five tiers of beams, 1 ft. deep, of yellow pine, placed one above the other and crossed, the beams being lightly connected by long bolts. The working chamber was 167 × 102 ft., and 10 ft. clear height. The side walls had a V section, with a cast-iron edge covered with sheet iron; the walls had a batter inside outwards of one to one, and one in ten on the outside. Five transverse wooden partitions 2 ft. thick at the bottom, served to regulate the sinking. When the caisson had been put in place, twelve tiers of beams were added on the roof of the chamber of the Brooklyn pier, and nineteen on that of the New York pier, so that the top rose above water, and the masonry could be built without a cofferdam lining. The excavation to the extent of 19,600 cub. yds. was performed in five months, by a scoop dredger, working in two large shafts, dipping into the water at the bottom and open above. When hard soil was met with, these shafts were shut, and the excavation performed by manual labour under compressed air. In the New York caisson the total number of shafts was nine. The blocks of trap rock impeded the progress considerably; they had to be discovered by boring, and shifted or broken before the caisson reached them. When under 26 ft. of water they could be blown up; this enabled the rate of progress, which had been 6 in. a week, to be doubled and trebled. When the caisson had reached a compact soil, it was possible to reduce the pressure to two-thirds of an atmosphere in excess of the normal pressure, and water had occasionally to be poured into the open shafts to maintain the proper water level in them. By frequent renewal of the air, a supply was furnished for 120 men, and for the lights; and the temperature was kept nearly constant throughout the year at 86° within the caisson, while in the open air it varied from 108° to 0°. As the load increased as the caisson went down, the roof of the Brooklyn caisson was eventually supported by seventy-two brick piers, so that the caisson might not become deeply embedded in the event of a sudden escape of air. In the New York caisson two longitudinal partitions were added, which served the same purpose.

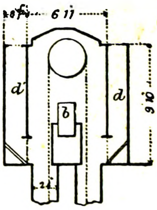
535.

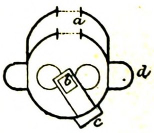


In the silty sand that was frequently met with, a discharge pipe, up which the sand was forced by compressed air, proved very useful, discharging a cub. yd. in about two minutes. The New York caisson, 170 ft. × 102 ft., was sunk in five months; the earthwork removed amounted to 26,000 cub. yds. The cheapness of wood in America permits a much freer use of it there than could be attempted in Europe.

When the water-tight nature of the lower soil in the foundations of the East River Bridge is considered, coupled with the inconveniences experienced in working under compressed air, it seems probable that in some future large work it may be possible to commence sinking a large caisson with compressed air, and after a better stratum is reached open all the shafts. The operation could then be completed by pumping out the small amount of water that might come in, and excavating in the ordinary way, as is often done in England, on a small scale, where the excavation to sink the cylinders to a water-tight stratum is performed by divers. If, as Morandière suggested, the air-lock was placed close over the working chamber, or even inside it, which would save constant alterations and allow of its being of larger dimensions, it would be desirable to have a special air-lock at the top, so that in the event of an accident the men might run up the shaft, without the delay occasioned by passing through the air-lock. At Bordeaux the air-lock was formed by fixing one circular plate on the top, and the other at the bottom of one of the rings of the cast-iron cylinder, so that it was unnecessary to remove it each time that an additional ring was added. To save loss of air, the air-lock should be opened very seldom, or made very small if required to be opened often. At Argenteuil the air-lock, Fig. 527, had an annular form with two compartments *c c'*, each having an external and an internal door. One compartment was put in communication with the interior to be filled with the excavated material whilst the other was being emptied by the outer door, so that the loss of air was diminished without any interruption to the work. Sometimes a double air-lock with one large and one small compartment is used; the large one being only opened to let gangs of workmen pass, and the small one just big enough to admit a skip and to contain a small crane for moving it. By having a small air-lock opened frequently, any sudden alterations in pressure are diminished. A more complete arrangement was adopted at Nantes, Figs. 536, 537. There a short iron cylinder was placed on the top of the double shaft in which the skips worked, having at one side a crescent-shaped chamber *a*, serving to pass four men, and also on either side two concrete receivers *d d'*, having doors above and below. There was a shoot below for turning the concrete into the foundations, and a box *b c*, holding a small truck which emerges at *c*, after having been filled

536.

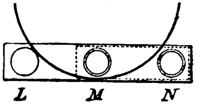




537.

from an upper door *b*. This last contrivance resembles that devised at Vichy, by Moreaux, Fig. 538. The cast iron box L N going across a segment of the air-chamber, has three orifices L M N, and a drawer, with two compartments, slides in it. If these compartments are at M and N, the left one at M is filled, while the other at N is emptied. Then, by a rack movement, the drawer is pushed back till the compartment to the right comes to the centre of the box, that is to say, into the air-lock, and the other is emptied outside at L. At Rotterdam Michaëlis put a small inclined trough at the bottom of the principal air-lock, and closed it at each extremity by a valve, so that it both formed a little independent air-lock, and also a shoot for the excavation. Smith employed the same system at the Omaha Bridge over the Missouri. By not permitting the earthwork to enter the principal air-lock, it was possible to keep six glazed bull's eyes clean, by which both daylight was admitted and at night the light was thrown from a reflector. The use of lamps inside, smoking and giving a bad light, was done away with.

538.



A. S. von Eisenwerth conducted some experiments to ascertain the amount of air actually required, for sinking wrought-iron caisson foundations by the pneumatic method. A rough rule, determined by practice, is that for a caisson having an area not exceeding 800 sq. ft., a blower capable of delivering about 12,000 cub. ft. of air an hour was sufficient. The old practice is to estimate the number of workmen and the number of candles employed inside the caisson, to reckon 220 cub. ft. a workman, and 11 cub. ft. a candle each hour, doubling the total to allow for loss. However, only 17 to 40 per cent. of the air pumped in for the benefit of workmen actually reaches them, and the loss by leakage determines the supply. The leakage through the air-pipes, air-lock, and shaft is small in comparison with that through the walls of the caisson, and is stopped to a considerable extent by plastering the joints on the inside with clay. In Eisenwerth's experiments the roof of the caisson, covered with a layer of cement, and a thick mass of concrete, was practically air-tight, except at its edges, where it joined on to the vertical sides. The leakage through these sides, in spite of the masonry lining, was by far the most important. It was found that during the first expulsion of the water from the caisson, the leakage through the sides alone caused a loss equal to 20 to 33 per cent. of the air theoretically required. The loss observed in various experiments, during the expulsion of the water, appears to be about 9·487 cub. ft. a sq. ft. of wall-surface in each working hour. The loss of air while the caisson was being sunk by excavation inside, varied between 9·843 and 17·225 cub. ft. a sq. ft. of side area an hour, according to the workmanship of the caisson and the nature of the soil. In coarse gravel and clay the loss was decidedly less than in fine gravel and sand, being on an average about 141·26 cub. ft. in the first case, and 153 cub. ft. in the second, for a medium depth of about 23 ft. Where the caissons are small, the relative loss is greater, because the blower pumps more air than is necessary, and part, therefore, escapes under the bottom edge; in this case, by an arrangement of valves, two caissons can be sunk together with the same blowing engine. As might be expected, the loss of air increases with the increasing depth of the caisson under water, the average increase being apparently about 10·76 cub. ft. a foot. Generally the result is shown that in caisson foundations the proportion of air used for passing the materials and workmen through the air-lock, and for keeping the caisson full of air against the increasing pressure as it descends, is only 1 per cent. of the whole, the other 99 per cent. being lost either through leakage or escape from the bottom.

Tubular foundations are the most effectual means at the disposal of engineers for carrying foundations to great depths below water. Economical considerations render it desirable to adopt pumping or dredging when possible; but compressed air is very serviceable where boulders or other obstacles are met with, or where the ground is conglomerated and unsuitable for dredging. In cases where the proper course to be adopted is a matter of doubt, the success at the Gorai Bridge, and the power of resorting to the aid of divers if necessary, would encourage an attempt being made to dispense with compressed air, which at great depths, such as 100 ft. under water, is attended with danger. The Tet Bridge, moreover, furnishes an example of the possibility of resorting at last to compressed air if found indispensable.

In soft ground of unknown depth the best methods for making foundations are those already described; but it is sometimes advisable in small works to adopt more economical methods. Two distinct cases have to be considered. Where the soil is firm, but liable to be scoured to great depths; Where the soil is soft as well as exposed to considerable scour.

Régemortes, at Moulins, renounced the idea of finding a stable foundation far down, and built on the surface, rendering it secure from scour by covering it with a masonry apron. The apron, Fig. 539, having a uniform thickness of 6 ft. was laid on the dredged and levelled bed, dried by diverting the stream, or in some places, by inclosing it with timber and pumping out the water. The infiltration through the bottom was stopped by depositing a layer of clay all over, and then lowering caulked timber panels in it. This method has, however, been much simplified by the introduction of hydraulic concrete. Another form of apron, Figs. 540, 541, was adopted at the Ain Bridge with a single row of sheeting at each end, $26\frac{1}{4}$ ft. from the facing of the bridge at the lower, and $11\frac{1}{2}$ ft. at the upper end. The lower or down-stream ends of the apron were always the most secured against scour, in the belief that a cavity would be formed below by the scouring away of the sand, but that above the currents would bring down sand and fill any hollows that might have been scoured out. The investigations however of Minard and Marchall indicated that the upper end of the apron is most exposed to scour and requires most protection, as the river-bed close to the lower end is protected by the apron, whereas at the upper end the river-bed is exposed to the full force of the current where obstructions of the piers produce whirlpools.

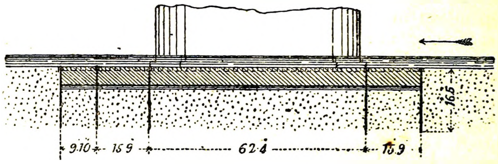
In certain instances the movable bed of a river has been sufficiently consolidated at the site of a work by merely a thick layer of rubble stones thrown in, giving time for the stones to take their final settlement during floods. Lastly, a movable bed can be consolidated by a wooden stockade.

The second case of a soil, both soft and liable to scour, has next to be considered. Where considerations of expense forbid going down to the solid, the following methods have been adopted;—

The ground is sometimes consolidated by driving a number of piles close together, or by covering it with rubble stones, with or without fascine work, so as to form a kind of superficial crust capable of bearing the structure. It is, however, generally advisable to break through the superficial stratum, and to produce a compression extending down a considerable depth by a large weight of earth.

Another method is to increase the bearing surface at the base by large footings, or by timber platforms, layers of concrete, bedding courses of masonry, or rubble stone.

539.



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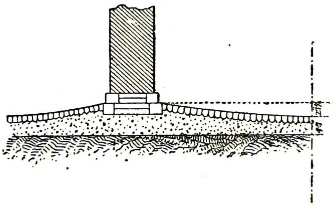
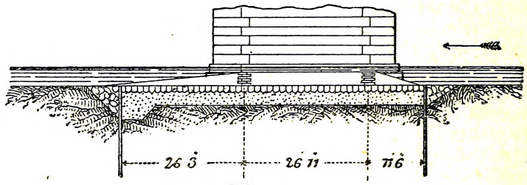




541.

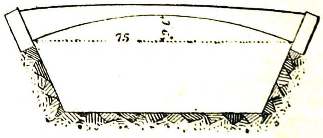
The weight of the superstructure can be diminished by forming hollow cells in the masonry, or by using iron girders instead of stone arches. In heterogeneous strata, the weight must be distributed as much as possible in proportion to the bearing power at different points. It is advisable sometimes to enclose the site of the foundations with sheeting, walls, or the like, not only as a protection against scour, but also to prevent the running in of the soil from the sides when a weight is brought on it.

Stone and Brick Bridges.—These have already been very fully treated, particularly with reference to the subject of skew arches. There are, however, several practical points of importance in connection with bridges of these materials which are deserving of notice. When stone is used it is chiefly for architectural effect and not economy. In former times cementing material was very inferior, and for stability it was desirable to have voussoirs in one piece; even now small bridges in the Highlands are so built without mortar of any kind. But at present the cement is as good as the stone, and it matters nothing how many pieces the arch wing is built up of, whether of a multitude of bricks, or a still greater multitude of particles of stone and cement in the form of concrete. The arch may be regarded in either case as a monolith, and the only conditions necessary to ensure stability are, that the curve of equilibrium shall fall within the thickness of the arch ring, to a sufficient extent to limit the pressure to the proper working strength of the material, which may be taken at 8 tons a sq. ft., for good ordinary stock brickwork.

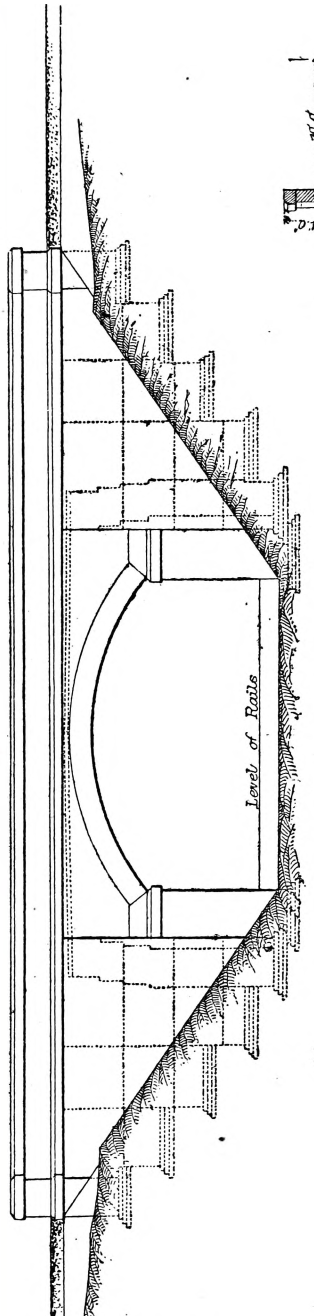
The largest stone bridge ever erected is the Grosvenor Bridge, crossing the Dee, near Chester. It has one clear span of 200 ft., its rise being 42 ft. The manner in which this arch was keyed in is worthy of remark. The courses contiguous to it being set, three thin strips of lead were first hung down on each side of the stones, between which the keystones were to be inserted. The keystones were then smeared with a thin greasy putty, composed of a mixture of white-lead and oil, and were driven home with a small pile engine. The object of the lead was to prevent the surface of the stones grating; it acted, in fact, as a kind of slide. In striking the centres, particular care was taken to keep the crown up and let the haunches come down. The Pont St. Maxence, blown up by Allies in 1814, is worthy of notice, as being perhaps the flattest stone arch, namely, 3 spans of 72 ft. arches with 5 ft. rise only and 3 ft. 9 in. voussoirs.

The reliable character of concrete exposed to compressive strains, is shown by the experimental bridge of concrete which was erected by Fowler, over one of the cuttings of the Metropolitan Railway, London, Fig. 542. It was an arch of 75 ft. span, 12 ft. wide, and 7 ft. 6 in. rise in the centre, where the concrete was 3 ft. 6 in. in thickness, increasing towards the transomes, which abutted upon concrete skewbacks. The material of which the bridge was made was formed of gravel and Portland cement in the proportions of 6 to 1, carefully laid in mass upon close boarding set upon the centering, and enclosed at the sides. The amount of concrete employed in the bridge was about 4800 cub. ft., so that the weight of the structure was some 300 tons. The centre of gravity in the half-span being 16 ft. 6 in. from the abutment, the weight of the half-span 150 tons, and the rise of the arch 7 ft. 6 in., the thrust at the crown was equal to 330 tons. A sectional area of 42 sq. ft. was available to resist the thrust which equalled 7 tons 17 cwt. a sq. ft. The additional strain a ft. run for every ton of distributed load was equal to $2\frac{1}{4}$ tons a sq. ft., maximum strain for a rolling load $3\frac{1}{4}$ tons a sq. ft. with the load at $\frac{5}{8}$ths of the span. This bridge upon test carried a dead load, including ballast and permanent way, of 12·25 tons, and a rolling load of 2·8 tons, or a total strain of 15 tons 2 cwt. on the sq. ft., without failure or distress. From this, it is fair to assume that a well-built concrete arch is as strong as one of brick, but at the same time the uselessness of

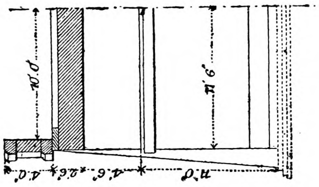
542.



inferior concrete work was shown by the previous failure of a concrete bridge of bad materials at the same place, which failed to carry even its own load.


Level of Rails

543.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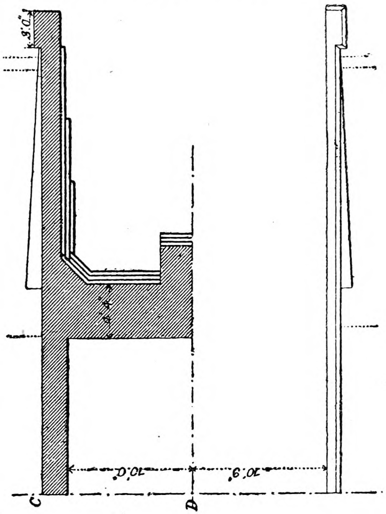
548.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4.4
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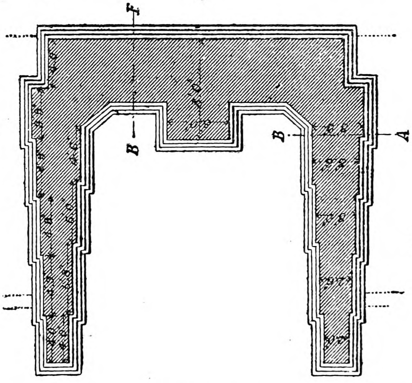
C
D

547.



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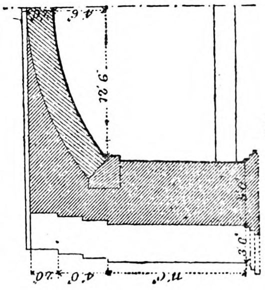
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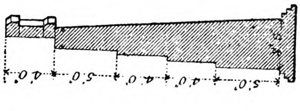
545.


4.0
5.0
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4.0
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3.0

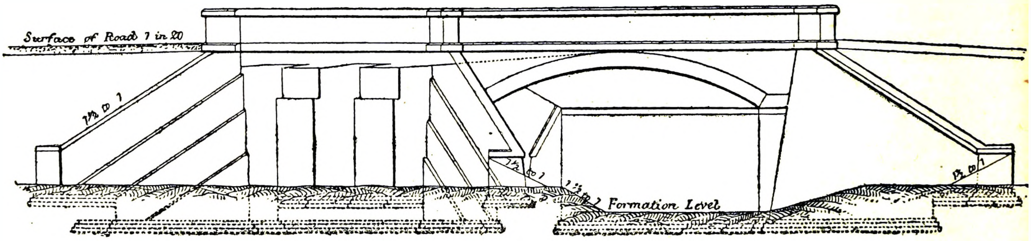
544.

On the continent of Europe many bridges have been built either of concrete in mass, or of blocks set as masonry.

Figs. 543 to 548 are an orthographic projection, of an ordinary stone or brick bridge on the square, over a railway in which the line is in cutting. Fig. 543 is an elevation; Fig. 546, plan above foundation footings; Fig. 547, plan of the under string-course; Figs. 544 and 545, sections at A B and B F respectively of Fig. 546; Fig. 548, section at C D, Fig. 547. If the cutting is very deep, so as to require a corresponding increase in the height of wing wall, Fig. 544, relieving arches are sometimes turned. There is, however, nothing gained by this arrangement, except perhaps in appearance, because although a certain amount is saved in the wing walls, it is more than compensated for by the quantity in the arch and the expense of centering and superior workmanship. The thickness of the wing walls is comparatively small, and the space between each pair viewed in the cross section of the plan of the bridge, Fig. 547, is filled with any material suitable for the purpose. When a relieving arch is turned in the wing wall, it must extend the whole length of this space; and except the cutting is sufficiently deep to allow of a semicircular arch, there is no economy in piercing the wing walls in this manner. The length of the wing walls depends upon the distance between two lines, representing the levels of the upper and lower roads, respectively. Should the bridge be wholly in cutting, the slope will extend from one of these to the other. Frequently, however, this is not the case, and the road has to be raised to some extent, as in Fig. 543. It is then usual to leave a small offset, or bench, at the point where the slope of the cutting intersects the surface of the ground, when the road is raised, in order to prevent the made earth from tailing down the slope of the cutting. The dotted lines in the elevation Fig. 543 show the position of the steps or offsets of the wings, counterforts, and abutments. Puddle, or asphalte, laid on the brickwork, Fig. 548, supports the road. When clay of proper quality can be procured, and if the work is well done, the puddle answers well. The walls of bridges are often backed with dry lining, consisting of small stones or broken brick, about 6 in. in thickness. This acts in the same capacity as drain pipes, or weeping holes.

Figs. 549 to 554 represent a working drawing of a skew bridge in embankment. Fig. 549 is an elevation; Fig. 550, transverse section in square; Fig. 551, plan of superstructure; Fig. 552, section of abutment on square; Fig. 553, plan of foundations; Fig. 554, section of wing wall. The different lengths and disposition of the wing walls prevent the bridge being symmetrical about its centre line, although the dimensions on the square are the same in both halves. Fig. 553 clearly indicates the effect of skew in increasing the general dimensions, and consequently the cubical contents of the whole structure. Working drawings upon a large scale are required for obtaining the development of the extrados and intrados, the spiral courses or coursing joints, and their intersection with the face line of the arch. When the length of the soffit of an arch on the skew is considerable, it is not uncommon to build the central portion on the square, and limit the skew part to

549.



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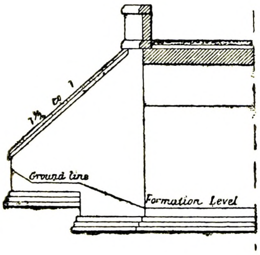

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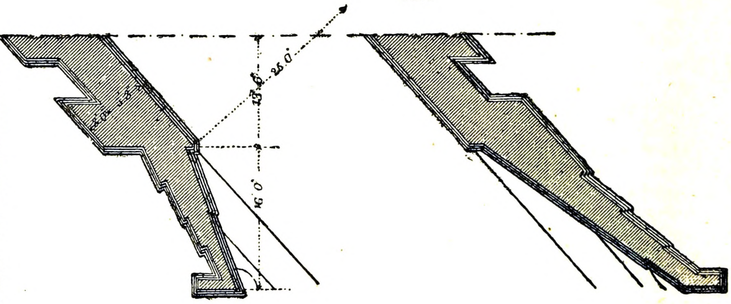

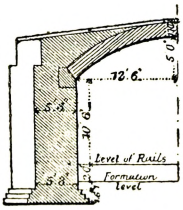

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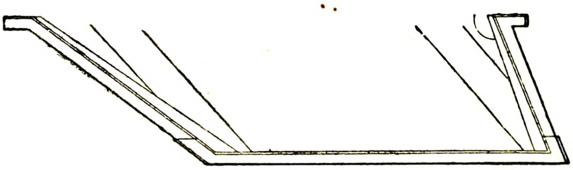

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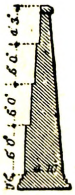


554.

the ends in the vicinity of the face line. If the junction of the skew with the square portion is well made, there is no practical objection to this method.

Abutments, Wing Walls, and Counterforts.—These portions of a bridge serve to support the pressure of the earth as well as to carry their share of the load, whether it be of the nature of a thrust or simply that of a vertical weight. The two working drawings, Figs. 543 to 548 and 549 to 554, fully explain the manner in which they act, and the useful purpose they accomplish. The methods of calculating their strength as retaining walls, when they reach dimensions of importance, will be found in the articles Retaining Walls, Construction, Waterworks. With the exception of the dressed work, such as string-course, quoins, caps, and copings, these parts of a bridge are generally built of the same description of work, a distinction being made between face work and the backing of the walls.

Iron Abutments.—Although there are numerous instances in which iron, both cast and wrought, is the material used for the piers or intermediate supports of bridges, the examples are by no means so common in which it is also employed for the terminal supports or abutments. It might appear, at first sight, that if the nature of the foundations rendered it advisable to adopt iron in the piers, the same conditions would dictate the use of iron in the abutments. But this is not always the case. In the first place, the character of the substratum in a tolerably wide river often differs at different parts of the transverse section, and it is seldom that both abutments are founded at exactly the same level. There is a notable difference in the nature of the ground on the Surrey and Middlesex shores of the Thames, for example, and a dam that would fully answer its purpose on the one might not always be sufficiently strong on the other. This fact was well shown during the construction of that portion of the Northern embankment near Blackfriars Bridge. A serious blow occurred in the dam, and yet this dam was almost identical in design to that which was employed during the building of the river wall from Westminster to Vauxhall, on the Surrey side of the Thames. On geological grounds alone, therefore, brickwork or masonry might be well adapted for the abutments of a bridge, and yet be superseded by iron, with advantage, in the more central and deeper parts of the stream. It is not, however, until we come to regard the different duties a pier and an abutment have to perform, which necessitate a diversity in constructive detail, that the real reason of the general unsuitability of iron for abutments becomes manifest; although there are many situations, as we shall point out, in which they may be employed to advantage. The sole duty that a pier has to perform, so far as relates to the bridge itself, is to bear the direct vertical pressure of so much of the superstructure as falls to its share. There are no doubt in many instances other forces in operation which try its stability and strength, such as the velocity of a marine or river current, the impact of ice, or the concussions of floating bodies, but these are beside our subject. It is otherwise with an abutment. In addition to bearing its own share of the direct weight of the superstructure, it has to act as a retaining wall. It will be understood that at present we are speaking of those forms of bridges which exert no thrust against either the piers or abutments. As every bridge must have an approach to it, which is most frequently of earth, it is the necessity of making the abutment support this that gives masonry or brickwork a general superiority over both cast and wrought iron. In many cases, however, it is convenient and economical to dispense with abutments and wing walls altogether, and simply put in a support similar to the intermediate piers, and allow the earth to assume the slope necessary for stability.

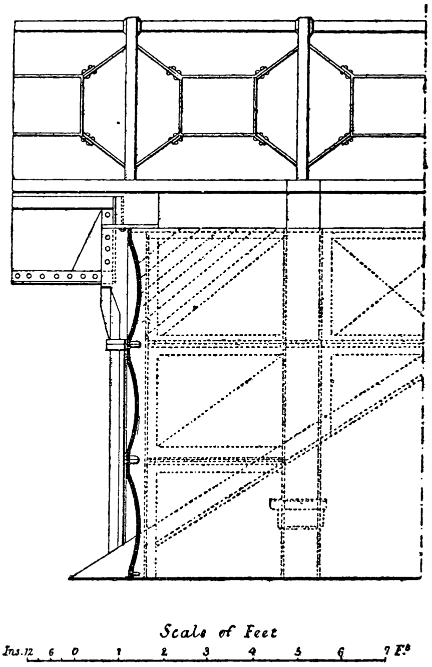
So far we have only taken into consideration that portion of the end supports which may be termed the abutments proper, but this is seldom sufficient of itself to retain the whole cross-section of the approach. The retaining wall, regarded as a whole, comprises not merely the central vertical part which carries the superstructure, but the side portions, or wings as well, which have no vertical load to support, see Figs. 543 to 548. It is in the wings that the chief difficulty of employing iron with economy occurs. In the abutment a certain degree of strength is required to carry the vertical load, and this amount can be simultaneously utilized as a contribution to the total necessary for the retaining wall. On the other hand, the wings act simply as retaining walls, having no vertical weight to bear, and the question becomes reduced to one involving the relative economy of iron and masonry or brickwork. Except in examples such as armour plating, targets, and engineering works of a warlike character, the substitution of iron for the older materials used in construction, will generally be found to be nearly equivalent to the substitution of the hollow for the solid form. Take the earliest, the cast-iron flanged girder. It is nothing else in form than a beam with the material cut away about the centre. The same statement holds good for wrought-iron girders, and the hollow column is only the stone pillar with its core extracted. It is not difficult to understand that a given amount of metal which would be able to support a given vertical weight would be quite inadequate to resist the same weight acting in a horizontal direction, or at an angle with the horizon. In the one case, supposing that there was no bending moment induced, the iron would only yield to a weight equal to its crushing pressure; in the other, the resistance it would give would depend upon the direction of the strain it was subjected to. Iron wing-walls will therefore evidently consist of plates to which the requisite amount of stability will be imparted by the addition of stays and bracing.

In the case of the New Ross Bridge the abutments and wing walls consisted of cast-iron cylinders with cast-iron plates fitting in between them, and a strong backing of concrete, which is equivalent to so much solid strutting or bracing. The design of the cylinders and plates is analogous to that constituting the foundations of the piers of Westminster Bridge, if we substitute piles for cylinders, the whole forming a cast-iron frame and panelling. The relative economy of this method of construction, depends very much upon the difficulties that may result from the presence of water. To build a retaining wall on dry land of cast-iron framing and panelling, to support a 25-ft. embankment, would be scarcely an economical proceeding; but to employ the same design in 25 ft. depth of water is another matter. As a rule it is certainly more expeditious to sink cylinders under water, and drive down panel plates between them, than to construct a temporary dam and build a solid wall of masonry and brickwork behind it. But it is not always so. Omitting the contingent difficulties in dealing with water, the actual cost of the two systems will differ to some extent, and the balance will in great measure depend upon the respective conditions already mentioned.

The question of durability must not be passed over. There are so many different opinions respecting the behaviour of cast and wrought iron, when exposed for some time to the action of either salt or fresh water, that no positive conclusion can be arrived at on the matter. Cast iron that has been exposed to sea-water has been found so soft that it could be cut with a knife; and, on the other hand, it has stood comparatively uninjured for years in almost exactly similar situations. It is alleged in favour of ironwork, that when it does rust the very rust itself acts as a protection against the further action of the cause that produced it. This may to some extent be true, but it must not be forgotten that rust never quite protected iron yet. The durability of cast iron in the position under notice will be lessened if there is a tidal action at work, as the effect of alternate exposure to water and air is not confined solely to timber, but extends to metallic substances as well.

A design for cast-iron abutments for bridges as proposed by Handyside & Co., of Derby and London, for bridges in Buenos Ayres, is shown in Figs. 555 to 558. The circumstances under which these bridges were required were peculiar, and demanded a special kind of structure. A vast extent of pampas of flat country was intersected by rivers, and the Government was desirous of improving the communication by erecting bridges, amounting to over a hundred, at all convenient points. As the country has neither stone nor timber, and as even bricks are not easily made or procured in the new district, Handyside & Co. proposed bridges which should be complete iron structures, with iron roadways, and with iron wing-walls and abutments, so as to be entirely independent of ordinary building materials. The mid-channel piles are formed of iron screw-piles. The foundation soil is of a calcareo-argillaceous character. As will be seen from Fig. 557, similar piles were proposed for the abutments, and to these piles are bolted a series of cast-iron plates, forming a complete face and side wings. Cast iron was preferred for this work rather than wrought iron, as being better adapted to resist the outward thrust of the banks, and as also best suited to the alternate wet and dry condition at the different seasons of the year. The superstructure of the bridges is entirely of wrought iron, and is strong enough to carry the carts of the country, which have heavy loads on a small wheel base.

555.



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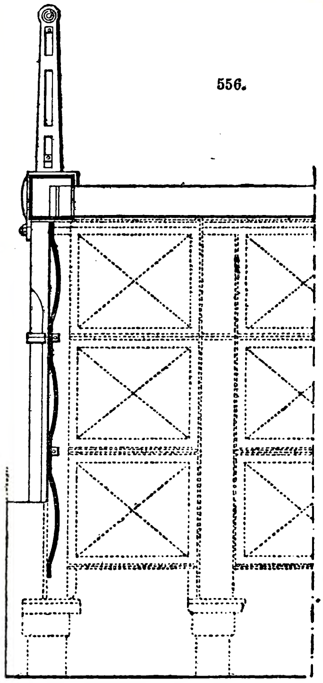

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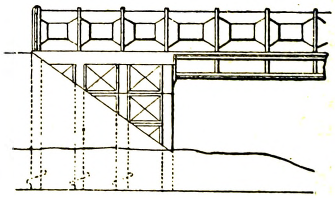
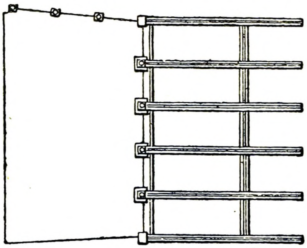
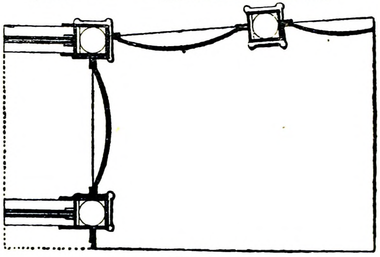


The Figs. 559 to 563, represent a design, by H. N. Maynard for a species of abutments of wrought iron. A considerable number of these structures have been successfully erected abroad. These abutments can be made complete at the ironworks, taken to pieces for shipment, and put together again by the aid of bolts in a very short time. The men who erect the girders can execute the work, and so all the difficulties and delays connected with the construction of masonry abutments, in such countries as India, are effectually avoided. The abutment consists of five solid wrought-iron screw piles, $4\frac{1}{2}$ in. in diameter, Figs. 559 to 563, braced together on Maynard's sleeve principle; the bracing being formed of wrought-iron arched plates, serving as retaining walls, and connected to the sleeves by means of bolts passing through flanges C formed on them. The outward thrust of the embankment, which is filled in between the wall of the abutment, is resisted by an arrangement of the rods D shown in Fig. 562. To facilitate transmission, the retaining plates are made with horizontal joints E, at about 2 ft. 9 in. apart, with angle iron forming flanges, by which they are connected together with a few bolts. In erecting this abutment the ground is first levelled at the parts where the iron walls are to be placed, and the screws with their sleeves erected in position, as shown in the plan; the bracing or retaining wall plates are then attached, and the front or bearing piles R, Fig. 563, driven by means of a capstan to the required depth, the other or back piles, G, serve to anchor the plates in position, and are attached to sleeves by bolts passing through them, whilst the front row are cut off flush with the tops of the retaining plates, and form a bearing for the bed of the girders. When long walls, such as those belonging to quays and water frontages, are built of either cast or wrought iron in the manner described, it is necessary at certain intervals to have additional braces and ties, and to extend them farther back. This is to render the construction in some respect analogous to that of long stone or brick walls. The extra braces take the place of the buttresses or counterforts, built at certain intervals, either at the front or back of all long retaining walls, to prevent their becoming distorted and bulging out. Cast-iron walls, insomuch as the thickness would be much greater than that of similar wrought-iron ones, would have more inherent stability in them than the latter. This can be readily compensated for by a proper arrangement of bracing in the thinner structure. As far as the relative cost is con-

558.





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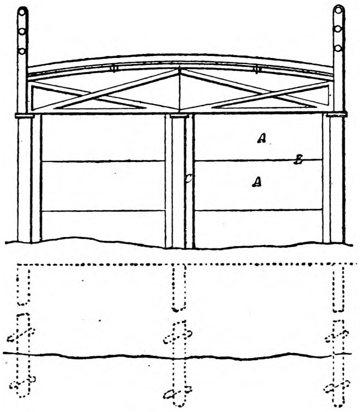

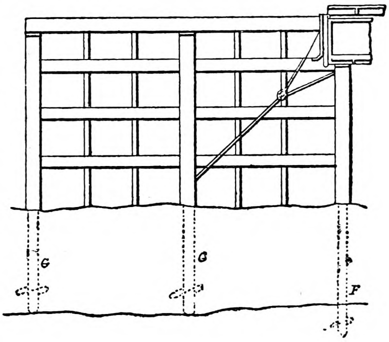

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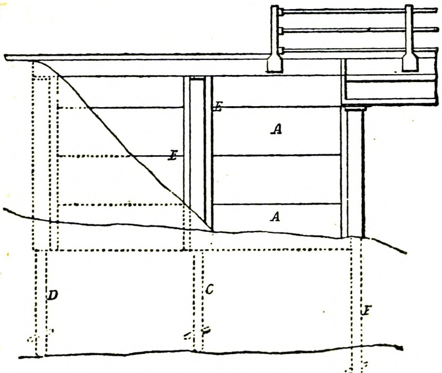

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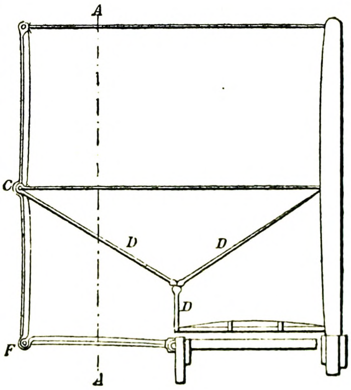
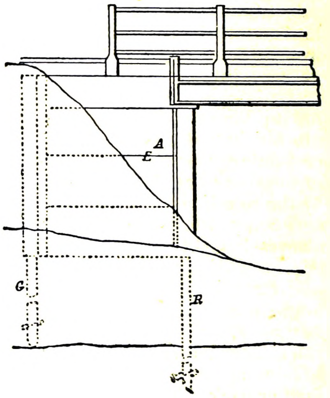


cerned, there would in many instances be little or no difference, as the greater amount of material in the one at a cheaper rate, would about equal the lesser amount at a larger price in the other. In instances in which rapidity of construction is a primary consideration, this method of building retaining walls possesses many advantages.

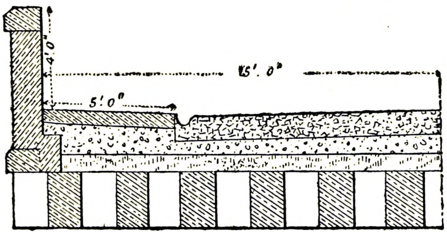
Numerous are the methods adopted by engineers and architects in forming roadways and footpaths over bridges, from the ordinary metalling and flagging, to boarding the whole area of the bridge over with inch boards, which is the method adopted in the Albert Bridge, as is shown in the section of that roadway.

563.



In Fig. 564 is represented a half cross section of the arch and roadway as usually arranged in stone or brick bridges. In the present instance, the arch is supposed to be of stone, which is shown alternately in section and end elevation, to point out that the coursing joints break joint. A very good form for the cross section of a roadway is to draw two lines at a slope of one in thirty, meeting at the centre of the road, and join them for a distance of 6 ft. by the arc of a circle having a radius of 90 ft., which will be practically flat, with just sufficient slope to allow the water to run off. The footpaths should have a fall of $\frac{1}{2}$ in. in the foot towards the side channels. Where metalling is used it should be at least 6 in. thick, and the depth from surface of road to masonry, should be sufficient to admit of small pipes being carried across the arch; large pipes are usually allowed to cut somewhat into the arch rings. Granite sets on concrete, wood paving, and asphalte are, of course, available for bridges as for ordinary roadways and footpaths, and offer no special features. A parapet is shown in Fig. 564, which, by the regulations of the Board of Trade, must be 4 ft. in height in every bridge coming under their jurisdiction.

564.



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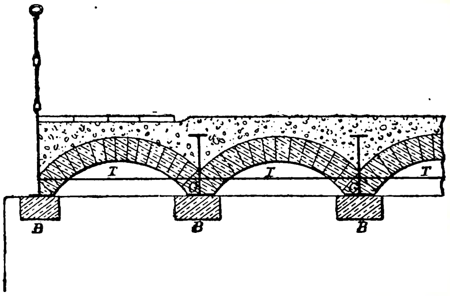
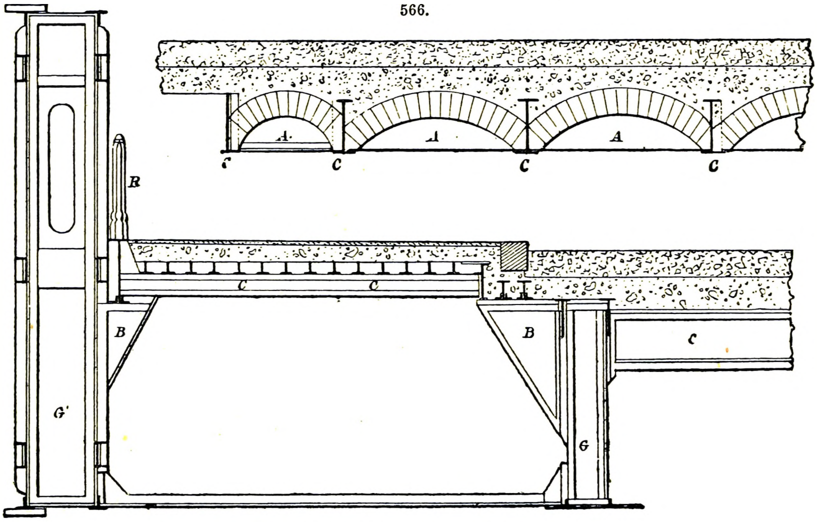


So soon as the horizontal girder became substituted for the arch, the arrangement shown in Fig. 565 was very generally employed. The cast-iron girders G G are carried on bed stones B B, a layer of felt being placed between the top of the bed stones and the bottom flange of the girders. It may be remarked here, that the width necessary to be given to the bottom flange of the girders, is very advantageous for the springings of the jack arches. In fact, this principle of construction would be naturally suggested by the form of the lower flange of the girders. The jack arches, which should not be less than 9 in. in the depth of the rings, are turned in the usual manner with plain mortar. There is no necessity for incurring the expense of turning them in cement, as is sometimes done. A layer of asphalte, shown by the thick black line, is spread uniformly over the extrados of the arches. The thickness of this layer need not exceed $\frac{3}{4}$ in., provided it be carefully laid on in two separate coats of $\frac{3}{8}$ in. each. The haunching of the arches up to the level of the crown, which is on the same level as the tops of the cast-iron longitudinal girders, may be filled in with broken brick, or other good, dry rubbish. Over this is laid the metalling, the depth of which should be about 9 in., and never less than 6 in. The footpath in Fig. 565 is supposed to be flagged with stones. The thickness of these may vary from 2 in. to 3 in.; but very often there is no choice in the matter, and shift must be made with the best that can be obtained in the neighbourhood. It will be observed that the outside longitudinal girder G′, or face girder, as it is usually termed, is made only about half as strong as the intermediate ones on account of its having much less weight to carry. The manner in which the thrust of the jack arches is provided for deserves attention. The thrust of each arch on one side of the lower part of the longitudinal girders is counteracted by that of its fellow on the other side, and this successive action and counteraction continues until we come to the arch, one springing of which bears against the inside of the face girder. Here there is no arch on the other side to take the thrust, which is thus thrown altogether on the face girder. The girder is, no doubt, strong enough to stand the thrust without any additional assistance; but in order to relieve it of the strain, a tie-rod T is carried at intervals right across the bridge, and ties all the longitudinal girders together. It acts in precisely the same manner as if there was but one arch, and it constitutes the tie from the one springing to the other. These ties may be placed at about every 6 ft. apart, and should be of good wrought-iron rod, not less than $1\frac{1}{2}$ in. in diameter. This roadway, carried on jack arches is seldom used for large bridges, as the weight renders it unsuitable.

There is, however, one example on a very extensive scale in Paris. It is the bridge at La Place de l'Europe, which carries the common junction of five main thoroughfares over a railway. The total area of roadway and footpaths extending over the bridge is about 8000 square yards, an extent of surface which is not often met with in structures over railways, if we except such cases as those in which stations are erected at a low level, and these seldom support so much. In Fig. 566 is represented a longitudinal section of a portion of the roadway of the bridge under notice. The cross girders C C are of wrought iron, with equal top and bottom flanges, instead of unequal flanges, as in the case of cast-iron girders, and are spaced 6·56 ft. apart, from centre to centre. Between them are turned the jack arches A A, which are 9 in. in depth, and weigh, the foot run, 0·145 ton. The peculiarity in these arches is that the bricks are not solid, but hollow, so that the wrought-iron main girders are not loaded so heavily as the cast-iron examples which have been already described. There was clearly the desire on the part of the designer of the structure to diminish the weight of the roadway as much as possible, and keep its general style in accordance with that of the rest of the structure. The black line in Fig. 566 shows the layer of asphalte, rather more than ½ in. in thickness, spread over the arches. The haunches are filled in with a description of thin concrete, which also extends over the crowns of the arches and the tops of the cross girders. This concrete weighs 0·108 ton a foot run, and over it is laid the metalling, which is 1 ft. in depth, and weighs to the same unit 0·356 ton.

566.



567.

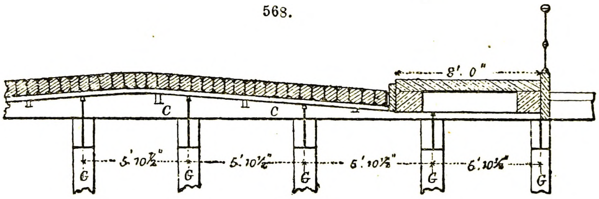
Some arrangement is evidently required to take the final thrust of the hollow brick arches supporting the roadway, as was explained in a former example, and the manner in which this is accomplished is very ingenious. It is manifest that although the arches rest upon the cross girders, yet the thrust of each half-arch is resisted by that of its neighbour, acting in the opposite direction. This process of thrust and resistance is continued until we come to the last half-arch, which has no fellow to take its thrust. This thrust is not taken by the abutment, but the last cross girder, upon which the arch rests, is tied by strong plate braces to the last cross girder but one, at the points where it bears on the main girders, thus transferring the thrust to these points. As an additional precaution, the last two arches are tied, the last by a solid plate diaphragm, and the last but one by a flat tie-rod. This arrangement makes the iron and brickwork to form one complete frame, so that if we were to imagine the whole superstructure lifted bodily from its support, it would still be self-contained. If the thrust of the last half-arches were taken by the abutments, the effects of the expansion, by alteration of temperature, of the main girders would be accumulated on them, and the consequences might be serious. By the method adopted the total expansion is subdivided at every cross girder, and the effect upon each arch is inappreciable. For small examples of bridges the plain tie-rod answered well enough, but when the roadway reaches the dimensions of the bridge at La Place de l'Europe, a more scientific and complicated arrangement is necessary. The footpaths are supported by small cross girders C C, shown in the longitudinal section, Fig. 567, and those in the centre part of the bridge, between the central face girder and the nearest intermediate, are the only ones requiring any consideration. They have a span of 14¼ ft., and are placed 6½ ft. apart. The total weight each carries, including the weight of the single T irons resting upon it and its own weight, is 8·5 tons. The single T irons under the footpaths have a maximum span of 8·69 ft., and their distance apart is 9½ in. from centre to centre. They are 3½ in. broad, by 4¾ in. deep, and have a uniform thickness of 0·39 in. The footpath consists of concrete covered by a layer of asphalte, and has a rather strong fall against the curb-stone. The cross girders are supported on brackets B, Fig. 567, which are riveted to the main girders G and G'. The former of these is the face or outside girder, and the latter one of the intermediate main girders. Both of these are lattice girders, and therefore it is necessary to put a handrail, R, as a protection to the foot passengers, as the lattice bars in the side of the face girders are not sufficiently close together to act as a parapet. It is not unusual to have plate girders with solid sides preferred to those of the lattice type, because by increasing the depth of the face girder it can be made to act as a parapet. There are two objections to this apparent economy. The one is that it is in reality a very expensive method of constructing a parapet, and the other that it constitutes a very unsightly one as well.

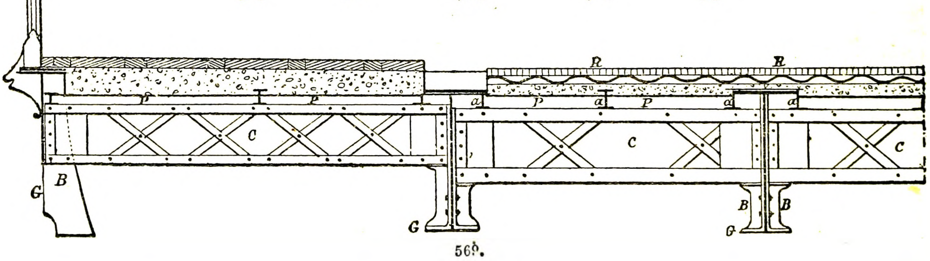
When bridges are built for street traffic, instead of that of country or suburban roads, there are one or two features which at once serve as a line of demarcation. In the first place, the roadway is usually paved, not as footpaths are paved, with flags, but with sets, as they are technically termed. These sets consist of stones, hammer-squared; that is, roughly dressed into the form of a solid 9 in. by 6 in. Several names are bestowed upon these sets, according to their size and quality. In some localities, more especially in the quarries in the neighbourhood of Leicester, they are called sovereigns and half-sovereigns, accordingly as they are of the full size specified above or of a smaller size, resembling those that are usually put down at the entrance to stables, farm-sheds, and courtyards. Sometimes the roadway of bridges, situated as just described, is constructed of wooden sets, similar in form and size to those of stone. It may be remarked here, that wooden paving has undergone a very extensive trial in London, and appears to wear well. There can be no question about the absence of the noise and racket which attends the employment of a stone thoroughfare in the adoption of the wooden road. The only point that remains to be settled is that of durability. It cannot be denied that if a roadway will stand the traffic of London, it will stand any traffic that can possibly come upon it, allowing in all cases for reasonable wear and tear. Another distinctive feature to be noticed in bridges, which may be appropriately called street bridges, is that the footpaths are usually paved either with flags or with some description of ornamental tiles. The latter method was originally adopted with respect to the footpaths of Westminster Bridge, but the tiles have since been replaced by asphalte.

In Fig. 568 is represented the cross section of the roadway of a bridge erected over the Medway, at the town of Rochester, which is in every sense a street bridge. The principals or main girders G G are composed of cast-iron ribs, spaced as in the figure. These are connected together by cast-iron cross girders C C, which are in separate lengths, each pair of lengths being bolted together by wrought-iron bolts at their junction over each main girder. The roadway is paved with sets of granite.

As a material for roadways, the Guernsey granite is preferable to the Aberdeen, as it does not disintegrate so fast. It is not quite so hard, and therefore does not wear with the same rapidity. The footpath in the bridge, Fig. 568, is paved with flags 6 in. in thickness. These flags are laid upon a couple of stone bearers 12 in. and 14 in. respectively in thickness. There is thus a fall of 2 in. in the footpath in the width of 8 ft. to allow the water to run off into the side channels. It is to be noticed that in Westminster Bridge the footpaths do not drain into the side channels of the roadway, but into others provided for them next to the base of the parapet.

568.



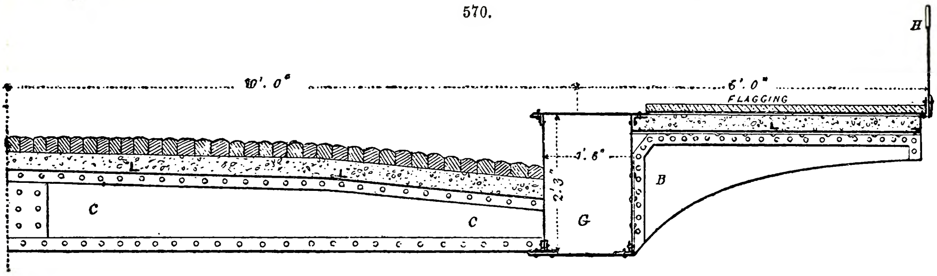


569.

Having already given sufficient examples of the method of constructing roadways over cast-iron girders, we may now turn our attention to those which are carried upon girders of wrought iron. In Fig. 569 is represented a cross section of half the roadway of Lendal Bridge in the city of York. The main girders are shown at G G; to them are bolted the wrought-iron gusset pieces or brackets B B, upon which rest the cross girders C C. These cross beams are small lattice girders, and have the great merit of possessing the features of strength and lightness combined. Upon the cross girders C C are placed the small wrought-iron rolled joists *a a*, and to the lower flange of these are bolted the corrugated iron plates P P. These plates extend the whole way across the bridge, both under the roadway and footpaths. Those under the roadway are $\frac{3}{8}$ in. in thickness, and those under the footpaths $\frac{1}{4}$ in. A greater degree of strength is obtained by the use of corrugated iron plates beyond that afforded by mere sheet iron. There are, however, two other methods of obtaining a similar, and even a greater, amount of strength. One is by bending the plates into the form of an arch, the other method is to employ buckle plates, which, comparatively speaking, possess enormous strength, and which have been used in some very large superstructures of bridges, the new Blackfriars Bridge, for example. Their great strength is due to their peculiar shape, which is that of a dome. The carriage or roadway R R in Fig. 569 is composed of several layers of material. In the first place, a layer of concrete consisting of cork and bitumen, 3 in. in thickness, is placed immediately over the corrugated iron plates. The object of introducing this light substance between the wrought-iron girder and the rest of the road material, is to deaden the concussion of passing loads, and distribute them more evenly over the girders, but it is an unusual and unnecessary refinement. Over this layer is placed another of ordinary cement concrete, composed of gravel and Portland cement, and upon this is laid the granite paving. The footpaths have layers of similarly composed concrete, and a paving of flags 3 in. in thickness. For a bridge constituted wholly of wrought-iron, this must be considered rather a heavy superstructure, in spite of the intermediate layer of cork concrete. Paving stones and York landings have considerably more weight than either wood or asphalte. If durability and efficiency can be obtained, the lighter the roadway and footpaths of a bridge can be made, the more economical the structure. In a road bridge the superstructure constitutes a very important item in the total load which the bridge has to support. In this point it differs from a railway bridge, in which the weight of the roadway itself is a mere trifle, compared with that of the loads which pass over it. In the London bridges, it will be seen, that even in the same type of bridge a different character of superstructure is adopted.

In Fig. 570 is represented the cross section of one-half of the roadway of Lambeth Bridge, the main, or side, girders G, which are supported directly by the chains, are built up of plates and angle irons in the ordinary manner. They belong to the old box form of girder, a form that is nearly obsolete. It was a good deal used in the early employment of wrought iron to the construction of girders. This fact was probably due to the idea that, owing to its particular shape, it was considerably stronger than any other form. This opinion has been since shown, experimentally, to be erroneous. If it be compared with a plate girder, containing the same amount of material, it will be a little the stronger of the two, but the slight increase of strength is not by any means sufficient to compensate for the other disadvantages it possesses. The principal of these are increased difficulty in riveting together, and no facilities for future examination when once put together complete. In the instance under notice the box girder has internal dimensions of 2 ft. 3 in. by 1 ft. 6 in. It is just possible that a boy might contrive to get inside to do any painting that might be required, and examine the interior generally, but anything like a proper examination is out of the question.

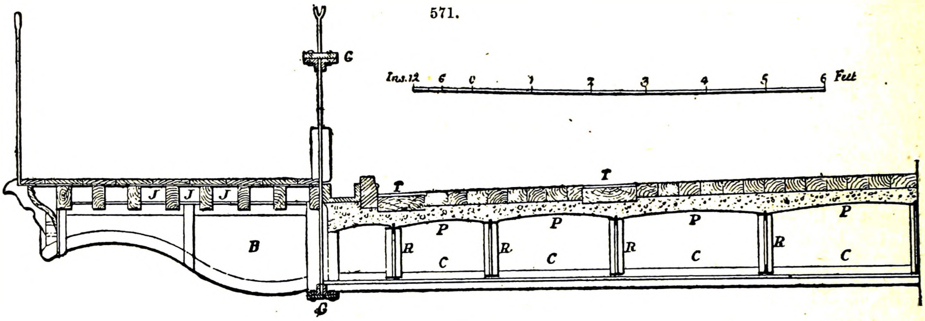
570.



The roadway in Fig. 570 is carried on the cross girders C C, which are of the plate type. These cross girders are riveted to the lower flanges of the main girders G, and constitute a strong cross brace between them, and very materially add to the stability of the whole bridge. They are cambered so as to give the proper curve to the road shown by the thick line. The platform is composed of wrought-iron plates, riveted to longitudinal and transverse wrought-iron beams, so that the roadway forms a horizontal girder of great strength to prevent lateral motion. The platform is suspended to the cable, not by vertical rods, but by rigid lattice sides riveted to the longitudinal beams of the platform. The lattice sides are intended to prevent the longitudinal undulation, which necessarily occurs in other suspension bridges supported only by vertical rods. It is further sought to check disturbance by attaching the cables to the standards, and not as hitherto done to a saddle allowed to move freely on rollers. The standards are constructed of wrought iron, and form an essential part of the design, acting in combination with the lattice sides to produce lateral rigidity. The roadway is formed of wooden sets laid upon concrete, as shown in the cross-section. The footpaths are carried on cantilevers B, riveted to the main girders.

A very different style of roadway is that laid over Chelsea Suspension Bridge, which is represented in half cross section in Fig. 571. With the exception of the light concrete filling over the arched wrought-iron plates, the whole of the roadway and footpaths are of wood. This description of superstructure has been objected to on the score of being liable to take fire, but the risk of its so doing is very small in a bridge confined to road traffic. It is well known that during the great fire at Chicago, the wooden pavement was readily inflamed, and railway bridges of timber have been known to be ignited by the platform, which was also of that material, catching fire from the hot ashes and cinders falling from the engine, but the danger becomes very remote in the instance of bridges devoted exclusively to the purposes of road street traffic. In the cross-section in Fig. 571, the transverse or cross girders C, which support the roadway, are placed 8 ft. apart from centre to centre, immediately under the suspension rods, and bear upon the bottom flange of the longitudinal girder G. They are 31 ft. 10 in. in length, 2 ft. $2\frac{3}{4}$ in. depth at the centre, and 1 ft. 11 in. at the ends, where they are connected by a system of riveting with cantilevers B, 7 ft. long, which practically form a continuation of them, and serve to support the overhanging footpaths. The sectional area of the top and bottom flanges is 10 in., and the vertical rib is $\frac{1}{4}$ in. thick, stiffened with ⊤ iron. The small roadway bearers between the transverse girders R are from 3 ft. 3 in. to 3 ft. 10 in. apart, 8 ft. long, and vary in depth from 1 ft. $5\frac{3}{4}$ in. to 1 ft. $9\frac{1}{2}$ in. to suit the cambered surface of the roadway.

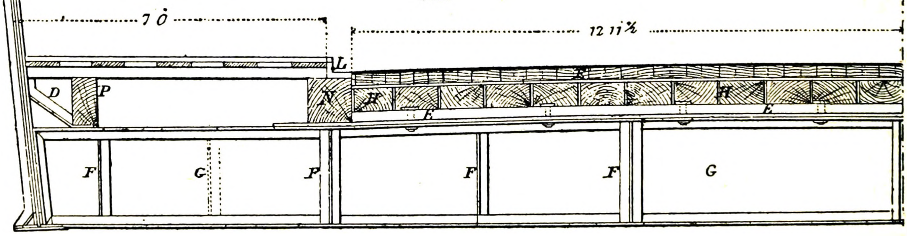
571.



The several girders that support the roadway thus form a series of rectangular cells, which are covered with arched plates of wrought iron P, stiffened with angle iron. The haunches of the plates are filled in with a light concrete composed of cork and bitumen, and, previously to laying the bitumen concrete, the plates and girders were coated with asphalte. The roadway is paved with oak blocks 6 in. by 3 in., by 4 in., bedded in bitumen, and furnished with trams T, of timber flush with the roadway, with wrought-iron strips bolted down on the top for durability. The preference was given to the cork and bitumen concrete, as a bedding for the roadway blocks, on account of lightness compared with ordinary concrete. Moreover, concrete in such a position, and in so thin a layer, is liable to crack, and become in time pulverized, and is then no better than loose gravel, which is liable to be deranged by passing traffic, and very soon wears into ruts and inequalities. The footpaths are paved in the same manner as the roadway, only the blocks are of smaller dimensions. This pavement rests on planking placed on joists J, running longitudinally, and resting on the cantilevers. The available breadth of the whole carriage-way is 29 ft., and footpaths 14 ft. 4 in.

Fig. 572 represents a cross section of half of the roadway of the Albert Bridge, at Chelsea. With the exception of the tiles which form the surface of the footpaths, the roadway is in every sense a timber one. As there are some peculiarities in the manner in which the different layers constituting the whole depth of the platform are arranged, we will describe them in detail. The side or main girders, a portion of one of which, M, is shown in the figure, are of the usual plate or solid type, and are made up of horizontal top and bottom flange-plates and angle irons which connect them with the vertical side or web of the girder. There is one peculiarity to be remarked in these main girders which is not to be met with in any similar structure. They are placed not in a vertical position, but with a cant, as in Fig. 572, and are retained at the proper angle by the cross girders, which are riveted to them. At intervals the main girders are carried by the suspension chains, to which they are connected by pins passing through the web, the junction being strengthened by circular wrought-iron gusset pieces and cast-iron bosses. This additional strength at the points in the main girders, at which the connection with the chains is made, is rendered indispensable by the severe shearing strain brought upon the web of the main girders. Theoretically, the total load on the bridge, including its own weight, is divided into as many parts as there are points of connection between the main girders and the chains. The separate weights, or the relative amount of the different subdivided loads, vary with the distances between the intervals of support, that is, with the distances between the successive pins. Another distinguishing characteristic of this bridge is, that the footpaths are placed inside the towers or pillars, and not outside, as in the case of the Chelsea Suspension Bridge and others.

572.

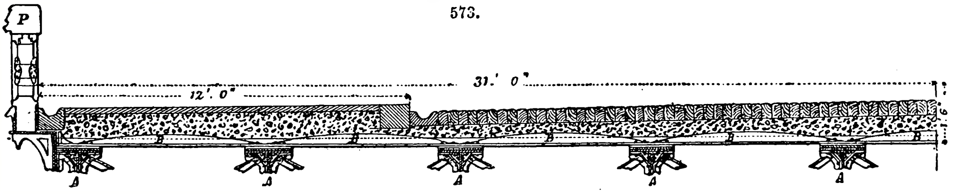


The cross girders G are of the same form of construction as the girders M, and are stiffened vertically by ⊤ and angle iron stiffening pieces, F F. The cross girders are riveted at each end to the main girders, and are also connected through the medium of their top flange. The stiffening vertical angle-iron D, of the main girder M, is bent or cranked while hot, and one end of it riveted to the top flange of the cross girders. The advantage of this additional connection between the cross and the main girders is, that the strain upon the latter is not confined to a mere portion of the web and lower flange of the main girder, but is distributed well over the whole cross section of it. The cross girders are, moreover, connected together by horizontal diagonal cross bracing of plate and angle iron, so that the whole combination forms an iron gridiron of great strength, durability, and lightness. It is to be noticed that the depth of the cross girders is not uniform, but is greater in the centre than at the ends. It is by this varying depth in the cross girders that the rise and proper curve are given to the roadway. A more usual plan is to accomplish this by making a difference in the thickness of the road crust or surface, and maintain the cross girders uniform in depth. The former plan is preferable. In the first place, if the latter be adopted, the thickness of the roadway itself must either be in excess at the centre or the reverse towards the sides. It is a mistake to imagine, as is frequently done, that the greatest amount of wear and tear upon a road takes place at or near the crown. Upon the contrary, experience has proved, especially where the traffic is considerable, that a part of the road occupying an intermediate position, between somewhere near the centre and the sides is the most severely tried. The most economical plan to adhere to, with regard to the proper formation of the contours of the roadway of a bridge, is manifestly to maintain the thickness of the road material itself uniform, and obtain the proper curve by varying the depth of the cross girders, road bearers, or whatever may immediately support the roadway, whether it be arched plates, corrugated iron, or other description of iron platform.

Passing on to the roadway, it will be seen on referring to Fig. 572 that a plank E, 3 in. in thickness, is bolted down, with bolts $\frac{3}{4}$ in. in diameter, to the cross girders. Upon these planks are laid the half balks H, 12 in. by 6 in., placed one inch apart. These extend over the whole platform of the bridge, and are covered by a complete decking of 1-in. planks nailed down to them, which constitutes an especial feature of this bridge. Upon this decking the wooden sets of the roadway are spiked. The sets are 9 in. by 4 in., and are of two kinds, double and single. The double are laid every fourth row, and are the only ones which are spiked down. This spiking down is more than sufficient to keep the rows of single sets firmly in their places. A layer of asphalte completes the formation of the roadway, and serves to bind all the timber crust well together. The footpath is supported by two balks, one, N, placed under the gutter L, and the other, P, close to the main girder. The gutter is of cast iron, of a simple angle shape, and acts both as a gutter for the drainage of the road as well as for the footpath. The fall in the footpath is obtained by making the two supporting balks of different depths, one, N, which carries the gutter, having a depth of 12 in., and the other, P, of 14 in. To these balks are spiked cross-bars, 3 in. in thickness, and nailed to them is a decking of 1-in. planks, laid with an interval of 1 in. between them. Upon the decking the tiles, $1\frac{1}{2}$ in. in thickness, are placed, forming the surface of the footpaths. They are of a whitish tint, with the exception of the rows nearest the main girders and the gutter respectively, which are of a bright-red colour. The whole of the timber is of the best Memel. The footpath, which offers the greatest security against unequal subsidence, and the consequent forming of pools in wet weather, is one which has the fewest joints. The greater the number of individual pieces, each of which can sink and become disturbed, independently of its neighbours, of which a footpath is composed, the greater the chance of its becoming uneven. In this respect, flags, although bad where improperly laid, are superior to tiles.

Another example of the road and footway of a bridge is represented in Fig. 573. Upon the main girders A A are fixed buckled plates B B, which are riveted down on the four sides. This increases their strength as a platform to a maximum. Upon the buckled plates concrete is laid, varying in thickness to suit the fall in the road towards the gutters. The surface is formed of wooden sets, and the whole flushed up with a layer of tar and sand laid on hot. The construction of the footpath is very similar, with the exception that the surface is composed of asphalte. The curb and gutters are of stone. Cast iron may be used instead of stone in the gutter.

573.



The platforms of railway bridges differ in some respects from those intended for ordinary road traffic. One of the simplest examples is shown in Fig. 574, in which the span is sufficiently limited to allow of the use of two small cast-iron girders G G. Planking 4 in. in thickness rests on the bottom flange of the girders, and the rails are spiked down to it. The cant is given to the rails by small wedge-shaped pieces of timber inserted between them and the planking. This cant may be given when cross sleepers are employed, by adzing a piece out of the sleepers. A somewhat similar arrangement is shown in Fig. 576, with the exception that whole balks of timber 14 in. square replace the cast-iron girders in Fig. 574. In large bridges, longitudinal sleepers are frequently laid over the planking, and the rails spiked down upon them. This plan serves to distribute the effect of a heavy moving load more uniformly over the entire platform of the bridge, and lightens, to some extent, the local strains upon the cross girders. These latter are, comparatively speaking, often the most heavily strained part of a railway bridge. In Fig. 576 it will be seen that the rails rest immediately over the centre of the main balks, instead of being carried solely by the planking as in Fig. 574. The rails are supported in the same manner in Fig. 575, where small wrought-iron plate girders are used instead of the balks. The girders simply rest on a layer of felt, and are bolted to the planking by fang-bolts at distances of 3 ft.

Weight of Roadways and Platforms; Working Load.—The weight a square foot of the roadways of public bridges, is a very important item in the total load they are designed to carry. Taking the respective weights in order and observing that they do not include the cross girders or any bracing, they run as follows;—

For brick arches turned either between the lower flanges of cast and wrought iron main girders, or between the cross girders, the average weight a square foot will not be less than 2 cwt. When arched wrought-iron plates, buckled plates, or corrugated iron is used, the weight will be about $1\frac{1}{2}$ cwt. In these weights a square foot, allowance has been made for metalling 1 ft. in depth. If wooden sets or planking, as shown in Figs. 572 and 573, be used, the weight will be correspondingly reduced, and may be brought as low as $\frac{1}{2}$ cwt. a square foot.

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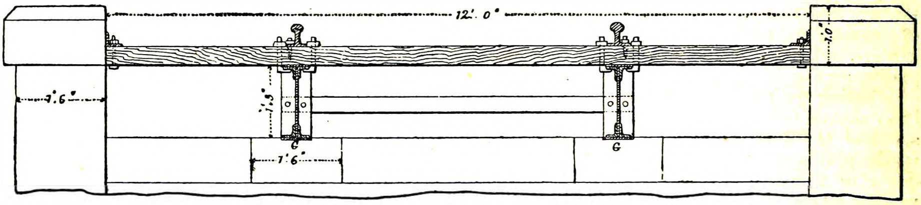

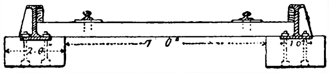

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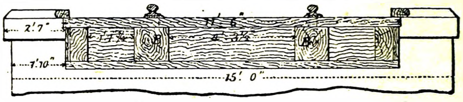

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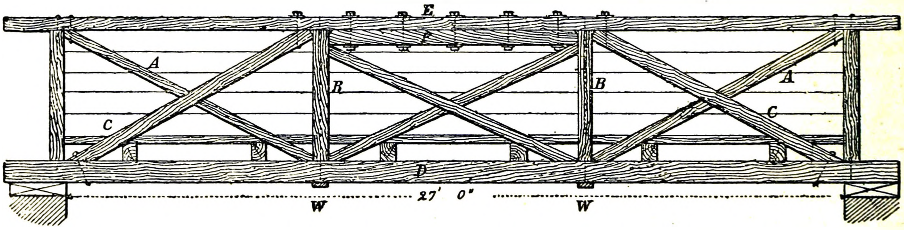
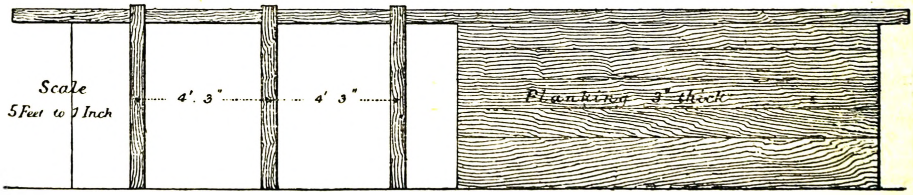
The maximum live load which can come upon any bridge, intended for ordinary road and pedestrian traffic, may be taken at 1 cwt. a square foot. The weight on many suspension bridges of large span has been estimated at 40 lb. a square foot, which Roebling from many observations has found to be about the maximum weight of a moving crowd of people. If the bridge is liable to be subjected to heavy concentrated loads, they must be provided for accordingly. Some of the modern city bridges of wrought iron have been constructed to carry heavy steam rollers, and contain more material than railway bridges of similar span.

Timber Bridges.—Bridges of timber, except for temporary purposes, or upon a limited scale, are nearly obsolete. They are, however, very useful in country districts where the span of the bridge is small, and the load to be carried comparatively light. A good strong, plain truss will then answer all requirements, and if taken care of and painted at proper intervals, will last a considerable time. The first cost is invariably much less than that of a stone or iron bridge. We give in Figs. 577 to 581 the working drawing of a truss frequently used for carrying country roads over a line of railway. The principles which govern the strains and arrangement of parts in this truss, obtain also in the largest examples, and therefore a general description of their action and the means of treating them will explain the subject. In the drawing, Fig. 577, the diagonal bars A A of the truss are not, theoretically, required, but are introduced for the sake of symmetry.

577.



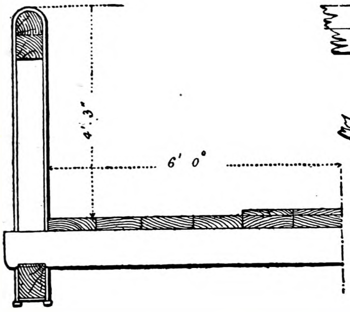


578.

The loading is placed on the lower member, and the truss thus acts as a parapet or hand-rail. The whole structure has a very neat and compact appearance.

The span of the truss, Fig. 577, is 27 ft., and the clear width inside 12 ft., and the total depth 6 ft. The total load on each truss is assumed to be supported at four points, namely, the two abutments and the points W W, where the uprights or posts are connected to the lower member or chord D. A strap, Figs. 579, 580, 2 in. by $\frac{1}{2}$ in. passes over the posts B B and the upper chord E F, and is keyed up tight under the lower chord or tie beam by a gib and cottar. The diagonal struts C C are fastened to the tie-beam by a bolt, but occasionally a strap is used instead. The different methods of connecting timber and iron in a bridge or roof will be found under the heads of Construction and Carpentry. Between the upper ends of the posts B B a straining piece F is fastened, and by bolting it to the upper member E, as shown in Figs. 577, 580, it may be regarded as forming part of it, and the sectional area may be made available in calculating the strength of the bridge. The joists of a timber bridge require to be comparatively strong, for like the cross girders of railway bridges, they suffer more from the force of any suddenly applied weight than the principal girders or trusses. So long as the planking remains sound, it serves to distribute the load pretty uniformly, but the planking is frequently allowed to get very much out of repair in all description of bridges, and the joists suffer proportionally. A layer of gravel or broken stone is usually spread over the planking of a timber bridge for two reasons; one is to preserve the timber from the feet of the horses, and the other from the risk of fire. The strength of joists and planking, of the quality ordinarily used for this class of work, should be estimated upon the basis of the breaking weight of a bar 1 ft. span and 1 in. square, being 2·5 cwt. applied at the centre. Thus the breaking weight for the 9 in. × 6 in. joists at the effective span of 12 ft. 6 in. would be;—$\text{B. W.} = 2{\cdot}5 \text{ cwt.} \times \frac{(9 \text{ in.})^2 \times 6 \text{ in.}}{12{\cdot}5 \text{ ft.}} = 97$ cwt. at the centre or 194 cwt. distributed.

579.



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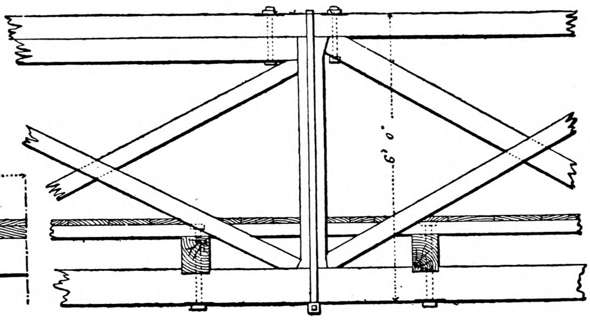
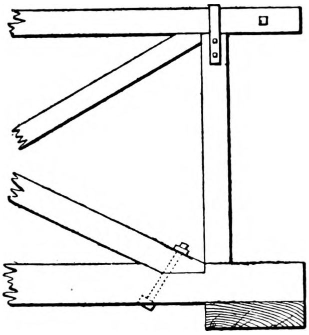
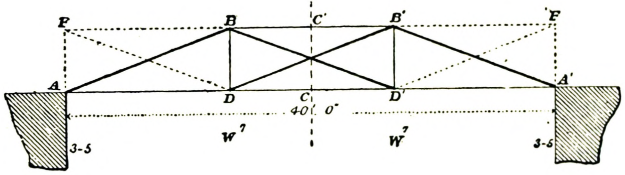


581.



Strains upon Trusses.—In estimating the strength of truss or girder work, it is necessary to distinguish struts from ties. Struts are members that are compressed, and ties members that are in tension. What members are in tension and what are compressed, may be determined by drawing the line from the point on which the straining force is exerted, in the direction it would take if the members were removed. If this line is incident within the angle formed by the pieces and the strain, then both pieces are in compression; when the line falls within the angle formed by producing the direction of the sustaining members, then both members are in tension. The following method is more general, and includes the foregoing case. Construct the parallelogram, taking the direction of the straining force as the diagonal. The sides of the parallelogram being parallel to the sustaining force, draw the other diagonal of the parallelogram, and parallel to it draw the line through the point where the directions of the forces meet. Consider towards which side of this line the straining force would move if left free, all supports on that side will be in compression, and all those on the other side in tension. At page 2818 of this Dictionary more special cases are considered. The diagram in Fig. 582 represents the actual working parts of the truss exactly similar to that in Fig. 577. The thick lines represent the parts in compression, and the thin those in tension. The annexed Table II. gives the strains upon the different bars for one half of the truss. The truss has a clear span of 40 ft., a depth of 5 ft., and the total load which is placed upon the lower chord is equal to 21 tons. The distribution of this load will be as follows;—At the

582.



points D and D^1 there will be 7 tons, and 3·5 tons will be supposed to rest directly upon the abutments. The weight of 7 tons at D will be borne by the vertical tie D B, whence it will be conveyed by B A to the abutment A, and a due proportion by the other members to A^1. The respective strains will be as follows;—Let L = span of truss, x = distance of D from the nearest abutment, W = total weight, and R R_1 = the separate portions of the weight. Then $R + R_1 = W$, $R = \frac{W \times L - x}{L}$ and $R_1 = \frac{W \times x}{L}$. From which R = 4·66 tons and R_1 = 2·33 tons. The first of these will produce compressive strains in the upper flange B C^1, and in the diagonal B A, and tensile strains in the vertical B D, and in the parts of the lower flange A D and D C. Similarly, the latter portion of the weight will compress the parts B D^1, B^1 C^1, and B^1 A^1, and stretch C D^1, D^1 B^1. A similar action arises from the weight of 7 tons situated at D^1, and the sum of the two gives the total strain upon the various members of the truss. These strains are tabulated in Table II.

TABLE II.

Weight at	Bars.						
	A B.	A D.	B C^1.	B D^1.	B D.	D C.	D B^1.
D	+13·40	−12·60	+12·60	..	−7	−12·60	..
	..	..	..	+6·70	..	..	..
D^1	+ 6·70	− 6·30	+ 6·30	..	−2·3	−12·60	+6·70
	+20·10	−18·90	+18·90	+6·70	−9·3	−25·20	+6·70

The strain upon the bar A B may be checked by calculation. It is known to be equal to $\frac{W}{2 \sin. \theta}$. To find θ, or the angle B A D, we have tang. $\theta = \frac{B D}{A D}$, or log. tang. θ = log. 5 − log. 13·333 + 10. Solving, log. tang. θ = 9·574021, and $\theta = 20° 33''$. Consequently the strain upon A B $= \frac{7}{\sin. \theta} = \frac{7}{0 \cdot 35102}$ = 19·94 tons, which is a sufficient approximation to the result obtained by the geometrical process. The dotted lines represent the hand-rail, which has nothing to do with the truss, theoretically considered. If B D or B^1 D^1 were made struts instead of ties, and the load placed upon the top, then the diagonals B D^1 and B^1 D would be in tension instead of compression. Moreover, if the dotted lines D F and D^1 F^1 were ties under the same circumstances, so that the force of the truss was represented by F, F^1, D^1, D, then, with a load only at B, there would be no strain upon the diagonal B D^1. But if there be a load of 7 tons upon B and B^1, and the strains be worked out for the truss represented by F, F^1, D^1, D, they will be found to be equal in amount to those already obtained for the truss A B B^1 A^1, although of an opposite character for the corresponding bars. The strains upon the flanges will be the same, both in amount and character, and they will be a maximum in all cases when the truss is uniformly loaded. The maximum strain that the truss will undergo will depend upon the position of the load, both with respect to the flanges and the distance from the abutments. In Fig. 582, if the load were placed upon the top member, that is, upon B and B^1, and both B, D, and B^1, D^1 were ties, then either would undergo its maximum strain when it was itself free from load, and the other apex loaded. If the load were placed on the lower member under similar circumstances, then the maximum strain would take place when both apices were loaded. Supposing B, D, and B^1, D^1 to be struts, the conditions of the maximum strains are exactly reversed under the same methods of loading. It would not make any material difference in a span so small as 40 ft., so far as the strains are concerned, which form of truss was employed, but there might be a slight gain by making the bars B D and B^1 D^1 struts instead of ties. In that case, the truss would take the shape of F F^1, D^1 D, and all the diagonals would be ties. The truss in Fig. 582 is suitable for either a uniformly distributed or a moving load, as the diagonals intersecting each other at the centre of the truss are counterbraced, and can act either as struts or ties as the position of the load may demand. The strains in Table II. are those upon one half of the truss, resulting from the combined action of the two weights situated at the points D and D^1. The strains upon the other half are precisely similar, but the action of the weights will be reversed.

The strains upon the other bars in the truss in Fig. 582 may be easily calculated. The strain upon each of the central braces B D^1, B^1 D, will be equal to the vertical component of their load, multiplied by the cosecant of their angle of inclination to the horizontal.

Timber is but little used in England for bridges of any importance, but they are still built in countries where it is abundant, and where other circumstances render the employment of metal inexpedient. American timber bridges do not last in good condition more than twelve or fifteen years, the wood being generally unseasoned, and shrinking much after being framed. When covered in to protect them from the weather and well cared for, any shrinkage of the braces being immediately remedied, it is said that these bridges will remain in good condition double the usual time, or about twenty-five years. Some English and continental bridges of timber have, however, lasted much longer than this. In any case they are liable to fire in warm weather, and when used for railway communication. If employed, the timber should be of excellent quality, seasoned, and protected by chemical treatment.

Unit Strain in Timber Bridges.—The unit strain, or safe working load, which may be put upon each square inch of timber, as determined from a large number of timber bridges constructed in the United States, for the different members of the bridge is as follows. Unit strain in upper chords in compression = 797 lb. an inch of nett sectional area; in struts or braces also under a compressive strain = 743 lb.; in lower chords in tension = 955 lb. The compressive strain should be less if the ratio of length to thickness be greater than fifteen to one, and in England it would be difficult to find a timber bridge in which the strains are greater than one-half those stated, or say from three to four cwt. a square inch. B. Baker's rule for timber struts with a factor of safety of five is;—Working load in cwts. a square inch $= \frac{3500}{350 + r^2}$ when r is the ratio of length to least thickness.

Iron Bridges.—In all instances where strength and durability are considered to be of greater importance than mere first cost, bridges of either cast iron, wrought iron, or steel, are the modern representatives of this description of engineering work. Of these three materials cast iron having been first employed for bridges, we shall commence with it, and shall give, in addition to the theory of the subject, a few examples of existing bridges and girders, which serve to carry roads and railways.

Cast-iron Arches.—Cast-iron arches were prior to cast-iron girders. Southwark Bridge, with its central span of 260 ft., and side spans of 240 ft., still affords, in one sense, an almost unrivalled specimen of a cast-iron arch. The distribution of material in it is not, however, such as to recommend it for selection for future imitation, since the arch ribs are little else than flat edge plates instead of being of a girder section.

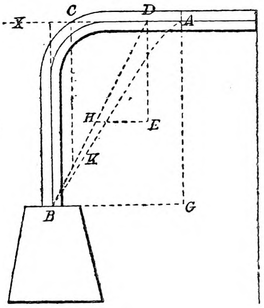
The theoretical part of the subject applies equally well to arched ribs of any elastic material, whether cast iron, wrought iron, or steel, and it will therefore not be necessary to recapitulate when we give practical examples of arched bridges of the two latter materials.

Strains upon Arched Ribs.—The general problem of the strength of arched ribs is one which, although it does not require for its solution the application of any very abstruse principles, sometimes involves very laborious and intricate calculations. For many practical purposes, however, it is possible to obtain solutions of particular cases by simple processes, and one of the means of simplification is to suppose the arched rib to be jointed at the crown.

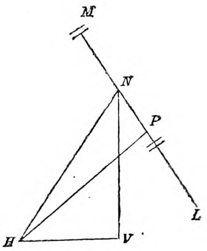
In Fig. 583 let A D C B be the neutral line traversing the centres of all the cross sections of a half-rib of any shape, abutting at its base B against an abutment, and jointed at its summit A to the summit of the opposite half-rib. Let the half-rib A D C B have a vertical load distributed over it in any manner. That vertical load will include that part of the load, if any, which is concentrated upon the end of the half-rib at A.

Having found by the ordinary principles of statics, the resultant load on the half-rib, draw D E vertically downwards from the horizontal line A X, to represent that resultant load in position and magnitude. Draw the straight line D B, and through E draw the horizontal line E H, cutting D B in H. Then E H will represent the horizontal thrust at every cross section of the half-rib, and D H will represent the resultant thrust at B, which is exerted by the foot of the rib against its abutment, and also the equal and opposite resistance which is exerted by the abutment against the rib.

583.



584.



The load and its distribution having been ascertained, we can calculate the vertical shearing actions, and from the vertical shearing actions calculate the bending moments, which would be exerted at a series of points in the half-rib if it were a bracket projecting from a vertical wall B X. Then from the horizontal axis A X, lay off vertically downwards a series of ordinates proportional to those moments, and on such a scale that the moment at X shall be represented by the ordinate X B. The ordinate corresponding to a given moment may be found by dividing that moment by the horizontal thrust E H; and conversely the horizontal thrust may be found by dividing the greatest moment, being that at X, by the rise of the half-rib X B = A G. Through the lower ends of the ordinates draw the curve of moments A B. For a uniformly distributed load it is well known that the curve of moments is a common parabola; that if there is no load concentrated at A, the vertex of the parabola is at A; and that if there is such a load the parabola at A has a slope proportional to it.

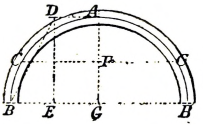
Find the pair of points, C and K, at which the curve of moments and the neutral line are farthest apart in a vertical direction; in other words, the pair of points in one vertical line where the tangents to those curves are parallel to each other. Then C will be the centre of that cross section of the rib at which the actual bending moment is greatest, and the greatest bending moment will be expressed by C K, H E; that is, it will be equivalent to the horizontal thrust acting with the leverage C K. The tendency of that bending moment will be to crush the inside edge and tear the outside edge of the rib. The bending moment on the rib at any other cross section, will be the product of the horizontal thrust into the height of the centre of that cross section, above the curve of moments. If at any point the neutral line of the rib lies below the curve of moments, the bending moment at that point is reversed.

In Fig. 584 let L M represent, in a side elevation of the rib, any given cross section, and N the neutral axis of that section. Draw N V vertically downwards, to represent the vertical shearing action at that cross section upon the rib regarded as a bracket. Through V draw V H, representing the horizontal thrust of the rib. Join N H; this will represent the resultant thrust at the cross section L M. From H let fall H P perpendicular to L M. Then P H will represent the amount of direct normal pressure at the cross section L M, which will be uniformly distributed, and will give rise to a compressive stress, to be added to the compressive stress at L due to the bending action; and N P will represent the actual shearing action upon the cross section L M, which in an arched rib will have to be resisted by the diagonal bracing.

At the section of the greatest bending moment C in Fig. 583 the resultant thrust is altogether normal, and the shearing action N P vanishes. The greatest shearing action in most cases which occurs in practice is that exerted at B, and throughout the vertical part of the rib, and it is equal to the horizontal thrust H; but there are some cases in which the shearing action may be greater.

The following are the results of the application of the preceding principles to a semicircular rib, Fig. 585, under a uniformly distributed load. Let the rise G A $= a$ and half the span G B $= b$. Let A denote the load that is concentrated at A; w, the load a unit of span on the remainder of the half-rib; x, the horizontal distance of any point from the vertical plane A G. Let r be the radius of the neutral line A B. Then the vertical load at B is $V^1 = w\,r = w \times \text{DE}$; the greatest bending moment is exerted at C, 60° from A, and tends to break the rib there, as shown in Fig. 586; being the same with the bending moment exerted by the same uniformly distributed load on a beam of half the span of the rib.

585.



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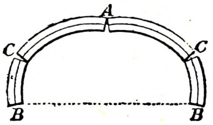

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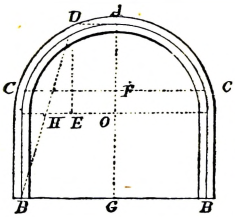

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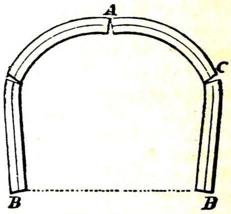


The normal pressure at C is $P = 2\,H = w\,r$.

If the load, instead of being w pounds on each foot of span, is w pounds on each foot of circumference of the neutral line A B, both the position of the point of greatest bending moment, and the amount of that moment, are very nearly the same as in the previous case; for the arc A C subtends about 62¼°; and the greatest bending moment is—

$$M' = 0\cdot124\,w\,r_2;$$

but the other quantities are different, being as follows;—

$$V_1 = 1\cdot57\,w\,r;\ H = 0\cdot57\,w\,r;\ P = 1\cdot23\,w\,r.$$

The case of a horse-shoe rib, in which each half-rib consists of a quadrant of the radius $r =$ O A, and a vertical leg of the height G O, forming with the quadrant a rigid rib of the total rise A G $= a$ is represented in Figs. 587 and 588. The load being uniformly distributed over the span at the rate of w pounds on each foot, draw the horizontal line A D $= \frac{r}{2}$; draw the vertical line D E meeting the horizontal radius in E; and join D B, cutting the same radius in H. Then D E represents the resultant load on the half-rib, E H the horizontal thrust, and D H the resultant thrust at B. To find the point of greatest bending moment, take O F $= \frac{r^2}{2a} = \frac{\text{O A}^2}{2\,\text{A G}}$, and through F draw the horizontal line F C. The greatest bending moment is $M' = \frac{w\,r^2}{2}\left(1 - \frac{r}{2a}\right)^2$; the vertical load at B is $V_1 = w\,r$ as before; the horizontal thrust is $H = \text{E H} = \frac{w\,r^2}{2a}$, and the normal pressure at C is $P = w\,r$.

To adapt the cross section of a rib to the bending moment M′ combined with the normal pressure P, let h be intended depth of the rib; $m'\,h$ the part of that depth which lies between the neutral axis and the compressed edge; q the ratio which the square of the radius of gyration of the cross section bears to the product $m'\,h^2$; and f the greatest intensity of the working stress; then the required sectional area is—

$$S = \frac{1}{f}\left(P + \frac{M'}{q\,h}\right);$$

all dimensions being expressed in the same units.

To find the intensity of the tension t, at the stretched edge of the cross section of greatest bending moment, let $m''\,h$ be the part of the depth of the rib which lies between the neutral axis and that edge; then

$$t = \frac{1}{S}\left(\frac{m''\,M'}{m'\,q\,h} - P\right);$$

all dimensions, as before, being expressed in the same units.

In a semi-elliptic rib springing from the ends of its horizontal axis and jointed at the crown, the principle of the transformation of structures shows, that the horizontal thrust is to the horizontal thrust of a semicircular rib of equal span, under an equal load similarly distributed over the span, as the radius of the circle is to the rise, or vertical semi-axis, of the ellipse; and by the aid of this principle, all the straining actions on a semi-elliptical rib may be deduced from those on a semicircular rib. The following are the resultant rules, in algebraical symbols, when the load is uniformly distributed over the span. Let w be the load on each unit of span, b the half-span, and c the rise; then the vertical load at the springing is $V_1 = wb$; the horizontal thrust is $H = \frac{wb^2}{2c}$; the greatest bending moment is exerted at a cross section the vertical height of whose centre above the springing is equal to $\frac{c}{2}$, half the rise of the rib; and that moment is

$$M' = \frac{Hc}{4} \quad \frac{wb^2}{8};$$

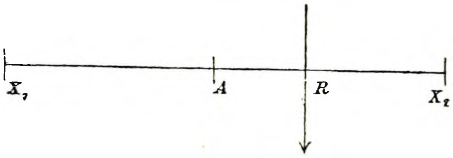
The normal pressure at that cross section is

$$P = \sqrt{(H^2 + \tfrac{3}{4} V_1^2)} = \frac{wb}{2}\sqrt{\left(3 + \frac{b^2}{c_2}\right)}.$$

In a horse-shoe rib, formed of a semi-elliptic arc with straight vertical legs, jointed at the crown and loaded uniformly over the span, let a be the total rise, so that $a - c$ is the length of a leg. Then we have vertical load at B, $V_1 = wb$, as before; height of the point of greatest bending moment above the horizontal axis of the ellipse, $\frac{c^2}{2a}$; horizontal thrust, $H = \frac{wb^2}{2a}$; greatest bending moment, $M' = \frac{wb^2}{2}\left(1 - \frac{c}{2a}\right)^2$; normal pressure at the cross section of greatest bending moment, $P = \sqrt{\left\{H^2 + V_1^2\left(1 - \frac{c^2}{4a^2}\right)\right\}} = \frac{wb}{2}\sqrt{\left\{\frac{b^2}{a^2} + 4 - \frac{c^2}{a^2}\right\}}$.

It is to be remembered that the preceding principles apply only to those cases in which the rib depends for its resistance to bending on its own stiffness alone, and not on the additional stiffening effect of bracing in the spandrils, or of abutting pressure transmitted through the spandrils; for the effect of such bracing and pressure may be, to make the real neutral line of the combined rib and spandril assume, a form quite different from that of the rib itself: so that, for example, a rib with a semicircular or semi-elliptic intrados may become merely a parabolic rib in disguise.

589.



When the load upon an arched rib jointed at the crown is unsymmetrically distributed, the pressures may be ascertained as follows;—In Fig. 589, let A be the crown of the rib, and let the horizontal line $X_1 X_2 = 2b$, which is bisected in A, represent the span. Let R represent the resultant load, which, if the distribution were symmetrical, would coincide with A, and let the deviation A R be denoted by x'. Then let V_1 and V_2 be the vertical pressures exerted at the springing joints which are below X_1 and X_2 respectively; then

$$V_1 = R\frac{b - x'}{2b}; \qquad V_2 = R\frac{b + x'}{2b}.$$

Let W_1 and W_2 be the two parts of the actual load, which directly rest upon the two halves of the span AX_1 and AX_2 respectively; and make

$$V_1 - W_1 = W_2 - V_2 = Q.$$

Then the load upon the half-span AX_1, namely $V_1 = W_1 + Q$, is to be treated as made up of the load W_1 which directly rests on that half-span, combined with an additional load Q concentrated at A; the load upon the half-span AX_2, namely $V_2 = W_2 - Q$, is to be treated as made up of the load W_2 which directly rests on the half-span, combined with a negative or upward load $-Q$ concentrated at A; and the state of strain on each half-rib is to be determined from those data, according to the method already described.

Practical Rules for Arched Ribs.

A = sectional area in sq. in. at the springing
A^1 = " " centre
A^2 = " " haunch

Then for round-ended arched ribs, $A = \frac{a}{t}$.

$$A^1 = \frac{a(b+1)}{2t - \frac{2rx}{d}}. \qquad A^2 = \frac{ab}{t - \frac{3rx}{4d}}.$$

For square-ended arched ribs,

$$A = \frac{ac}{t - 15rx}; \qquad A^{1 \cdot \cdot 2} = \frac{a(c+1)}{2t - \frac{3rx}{d}}.$$

Here t = tons a square inch on the metal; W = total distributed load in tons; w = ratio of total load to rolling load; r = ratio of span to rise of arch;

$$a = \frac{W\,r}{8} \sqrt{1 + \frac{16}{r\,2}}; \qquad b = \frac{\frac{d}{4\,r} + \frac{3}{4} + w - 1}{w}; \qquad c = \frac{\frac{d}{5\,r} + \frac{3}{4} + w - 1}{w};$$

and the value of x, in England, = 1·62 for cast iron, 2·75 for wrought iron, and 3·44 for steel; and in countries, such as America, where there are great extremes of temperature, about two and a half times these amounts.

The strain t, in tons a square inch, may in ordinary cases be taken at 3 tons for cast iron, 4 tons for wrought iron, and 7 tons for steel. In several existing bridges, however, the actual strain is at least two-thirds greater. When the web constitutes an appreciable proportion of the whole cross section, as is the case with cast-iron arches, the effective area of web should be taken less than the actual area in the proportion of $w - 1$ to w.

It is just a century since the first cast-iron arched bridge was erected. It was built across the Severn, near Coalbrookdale, Shropshire, in a single semicircular arch of 100 ft. diameter. This first experiment with the new material was not a perfect success. The semicircular form was ill adapted for such a structure; and there does not seem to have been sufficient allowance made for the difference between a solid and an open spandril. The result was a partial fracture of the arch. The next cast-iron bridge was built across the Wear, at Wearmouth, near Sunderland, in 1796. This time the form was segmental, the span of the arch being 236 ft. and the rise 34 ft. About the same date there was one erected by Telford, near Shrewsbury, the chord of the arch in this case being 130 ft. and the rise 14 ft. Telford seems to have been so fully convinced of the fitness of cast iron for bridges of large span, that a few years later, in 1800, he and Douglas prepared plans for replacing old London Bridge by a single arch of 600 ft. span. Their design was submitted to a committee of the House of Commons, then considering the question of rebuilding the bridge. The committee took the opinion of those best qualified to judge of the feasibility of the design; and, although it appears that those consulted differed widely as to the nature of the strains in the proposed arch, they were unanimous in considering the construction of a cast-iron arch of 600 ft. span as perfectly practicable. It was ultimately decided to build a stone bridge, but the reasons which lead to this decision, do not seem to have been due to any misgivings as to the power of carrying to a successful issue a project of so novel and bold a character.

From this time, the beginning of the present century, cast-iron arches increased in general favour, many of them being built in different parts of the country; and when the best means of carrying the Chester and Holyhead Railway over the Menai Straits came to be considered, one of the proposals was a cast-iron arch of 450 ft. span. Whatever advantages may be claimed for girders, and they are doubtless many and great, yet it must be allowed that when considerations of beauty form an element in the design, the girder must give place to the arch.

The ribs of which arches are composed are generally cast in several pieces, which have their ends carefully planed, so that those which are in contact may fit accurately when the rib is in place. They are then bolted together through flanges cast on the end of each segment. The consequence of securing the segments together in this way is that the rib is capable of resisting tension as well as compression, differing in this respect from voussoir arches, which can only be relied upon to resist compression, as the adhesion of mortar, or even cement, is considered too feeble or too uncertain to warrant its being taken into account, as capable of resisting forces which tend to open the joints of the masonry. The commonest form of rib is the segment of a circle, with a rise of about one-tenth the span, the section of the rib being the I, the depth of which increases slightly from the crown to the springing. Ribs of this form are designed of sufficient strength to bear the whole load, the only estimated function of the spandril being that of transmitting the load from the roadway to the rib. In cases, however, where the span is so small that the rib can be cast in one or two pieces, it is usual to make the top flange horizontal, and to cast the spandril in the same piece with the flanges. That is, the web of the rib forms the spandril, which is consequently taken into account in estimating the section required for a given load.

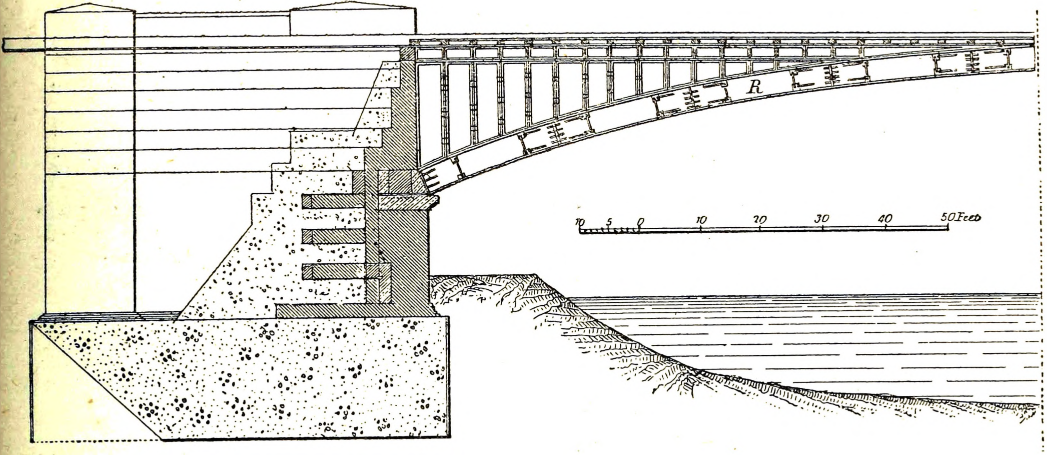
For some additional information with reference to the strains upon arched ribs and the analogy between the central strain upon an arch and a girder, see the article on Roofs in this Supplement.

Cast-iron Arch Bridges over the Severn.—Figs. 590 to 603, two railway bridges which cross the Severn, the one at Areley, near Bewdley, the other on the Coalbrookdale line, which is a short branch of the Severn Valley. The first-named work was completed in 1861, and is known as the Victoria Bridge; and the latter, opened in October, 1864, was named the Albert Edward Bridge. They were designed by John Fowler, and are of identical dimensions, and although not quite the largest arches ever constructed, they are the largest cast-iron arched spans yet erected for carrying railway traffic. A description of one will suffice for both.

With a span of 200 ft. in the clear, and a width of 27 ft. 6 in., the Albert Edward Bridge stretches from abutment to abutment, giving a headway from the surface of the water to the under side of the main ribs of 40 ft. The rise of the arch in the centre is 20 ft., or one-tenth of the span, and the depth of the curved girder 4 ft.

The strength and arrangement of the abutments will be ascertained from Figs. 590 to 592, which are respectively longitudinal, horizontal, and transverse sections. The foundations are entirely surrounded with sheet piling, which encloses an area 66 ft. long by 34 ft. 9 in. wide and 19 ft. 6 in. deep. This space is filled with 1650 cubic yards of concrete, and forms the foundation on which the abutments are constructed. The level of the ground is 3 ft. above the surface of this mass of concrete, and 14 ft. below the springing of the main ribs, to which height the face of the abutment is built in solid brickwork 8 ft. thick. The arrangement of the moulded stone course beneath the springing and the skewback is shown in Fig. 590, the brickwork behind the skewback being set in cement, bonded with iron, and convenient recesses are left beneath for the reception of the holding-down bolts, which secure in their places the cast-iron shoes in which rest the rounded ends of the main ribs. From the top of the skewback to formation level, the abutment has merely to retain the earth contained within the face and wing walls, and the thickness is gradually decreased from 8 ft. to 2 ft. 7½ in. The face of the abutment is strengthened by concrete backing, increasing from a thickness of 1 ft. 6 in. at formation level to 33 ft. at the foot of brickwork, Fig. 590; and three rows of horizontal arches transfer the thrust from the face of the abutment to the wing walls. These latter have a thickness of 7 ft. 2 in. at the base, gradually decreasing, as the pressure of the retained earth diminishes, to 2 ft. 7½ in. at formation level, and they are tied together with four 2½ in. diameter bolts. Externally the abutments present a symmetrical though not highly ornamental appearance; they are of brickwork, with stone mouldings and parapets.

590.



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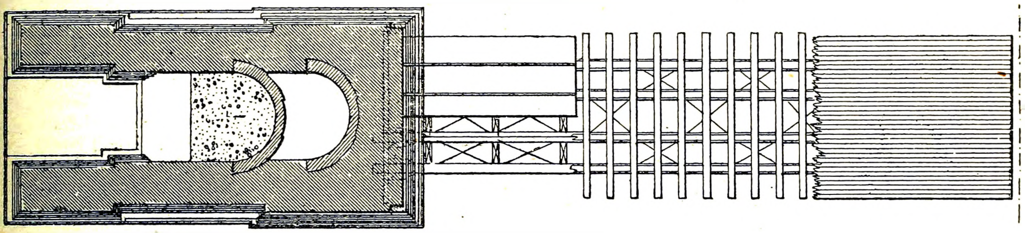

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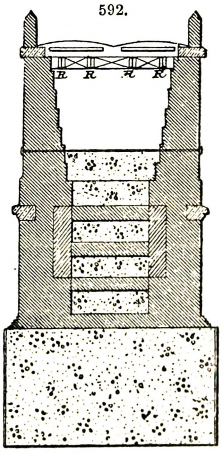

There are four main ribs, R, R, Figs. 592 and 593, placed 4 ft. 11 in. and 6 ft. apart, so that the centres of the ribs coincide with the position of the line of permanent way. The general construction of the main ribs is shown in Fig. 590, and in cross section, Fig. 593, as well as in detail, Figs. 598, 599, and 604. They are 4 ft. in depth in the centre, increasing to 4 ft. 9 in. at springing, with a top and bottom flange 1 ft. 3½ in. wide, and 2 in. thick, which also is the strength of the web. Nine segments, each 22·81 ft. long, with the intrados curved to a radius of 260 ft., complete the rib. The construction of the end segment is shown in Figs. 598 and 599, where it will be seen to terminate with a rounded heel, curved with a radius of 2 ft. 5½ in. and strengthened transversely and longitudinally with ribs and feathers. This rounded end fits into a curved shoe, which is held down to the abutment by seven 2-in. bolts 6 ft. long. The shoe is 3 ft. in breadth, corresponding to that of the main rib, which is widened out as shown in the plan, and 6 ft. long over its bed-plate, the thickness of metal averaging 2½ in. Both shoe and heel of main rib were cast to as nearly a true fit as could be obtained, and afterwards the surfaces were faced, and ground one on the other, so that extreme accuracy of contact was obtained. It is found, however, that the girders do not turn at all upon these joints, but rise and fall in the centre with the variations of temperature.

Horizontal wrought-iron girders 2 ft. deep, and of section Fig. 596, rest on the top of the spandril filling, bearing at one end, on the abutments, 22 ft. above the springing, and merging into the main ribs, at a point 18 ft. from the centre of the bridge. The upper and lower flanges, however, are continued until they meet the corresponding girder on the other side. These girders are of ordinary construction, with a constant cross-sectional area throughout of $8\frac{1}{4}$ square inches. The thickness of web is $\frac{7}{16}$ in., and the top and bottom angle-irons are $3\frac{1}{2}$ in. × 3 in. × $\frac{1}{2}$ in.

Stiffeners of the construction shown are placed 8 ft. apart, at the joints of the web-plate, which are made good with $\frac{1}{2}$ in. covers 1 ft. wide by 1 ft. 4 in. deep. Intermediate T-iron stiffeners are also placed at intervals of 8 ft. The cover plates of the bottom flange are placed on the inside of the girder, so that the web has to be notched, and the angle irons cranked, to accommodate the extra thickness. This is done to preserve a perfectly flush surface on the under side, and all rivets have countersunk heads for the same purpose.

The spaces between the under side of the horizontal girders and the main ribs are filled in with cast-iron standards, as shown in Fig. 590, and in details, Figs. 597 and 604. The standards are placed 4 ft. apart, from centre to centre; they have a cruciform section, and vary in size from 12 in. × 6 in., $1\frac{3}{4}$ in. thick, to 9 in. × 6 in., $1\frac{1}{4}$ in. thick. In each case they are cast in 4-ft. lengths, the joints being made with $1\frac{1}{4}$ in. diameter bolts midway between the standards, as shown in detail, Fig. 604. On the lower side they are secured to the main arch rib by 1 in. diameter bolts, placed 12 in. apart, and at top they are fastened to the horizontal wrought-iron girder by $\frac{3}{4}$-in. bolts, 8 in. apart, which alternate with the rivets in the bottom flange of the girder. Horizontal struts, of the construction shown in Figs. 600 and 601, are placed between the main ribs, and bolted thereto. The distance between them varies from 16 ft. 6 in. to 8 ft. 4 in., the space being governed by the length of the spandril standard. These struts are formed from two channel-iron rolled beams, $4\frac{1}{2}$ in. deep, $\frac{1}{2}$ in. thick, and $1\frac{1}{2}$ in. wide across the top and bottom tables, placed back to back, and riveted together, except at the ends, where they are opened out sufficiently to admit one web of the spandril standard, while the ends are turned back to bear against the other web, to which they are fastened by two $1\frac{1}{4}$ in. diameter bolts. Fig. 593 shows the method of vertical cross-bracing between the main ribs, adopted for this bridge. It consists of a series of cast-iron struts of the section shown, the top and bottom horizontal members being circular, and 4 in. in diameter, and hollow to admit of the passage of a $1\frac{3}{4}$ in. diameter bolt, which secures them to the main ribs. There are two sets of struts to each segment, or eighteen altogether in the whole length. At the top and bottom of these struts, tie-rods, $1\frac{3}{4}$ in. in diameter, extend diagonally from rib to rib, forming a thorough system of horizontal bracing throughout the bridge. The spandril standards are tied together vertically by diagonal bracing rods 2 in. wide by $\frac{3}{4}$ in. thick, and horizontally by bars of the same scantling, which do not cross each other, but are turned round at a distance a little short of the centre of each bay, and are bolted together by $1\frac{1}{4}$ in. diameter bolts passing through iron distance pieces, which are suspended from the platform overhead, Figs. 594 and 595. The wrought-iron girders underneath the roadway are also similarly braced, horizontally and vertically, in each case with tie-rods $2\frac{1}{2}$ in. by $\frac{5}{8}$ in.; struts, formed of two T irons $1\frac{5}{8}$ in. by $3\frac{1}{4}$ in. by $\frac{9}{16}$ in., are bolted horizontally to the bottom flange of the girders, as well as to the top of the spandril filling, as shown in Fig. 597.

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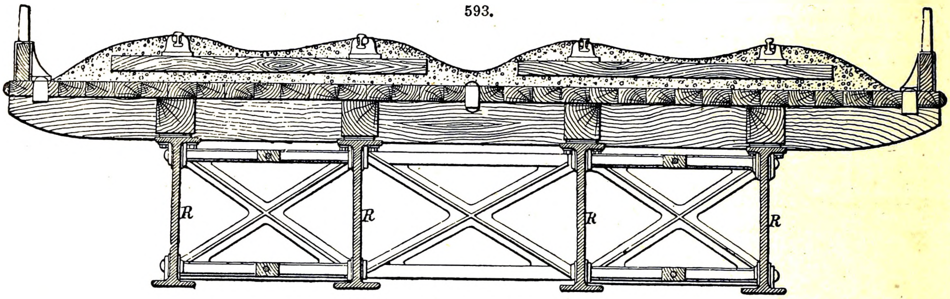

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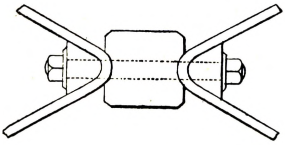

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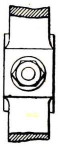

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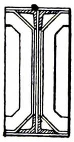

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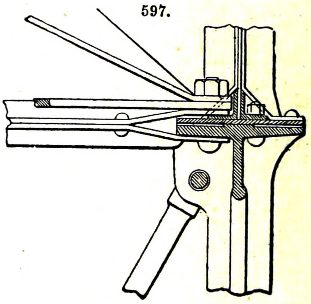
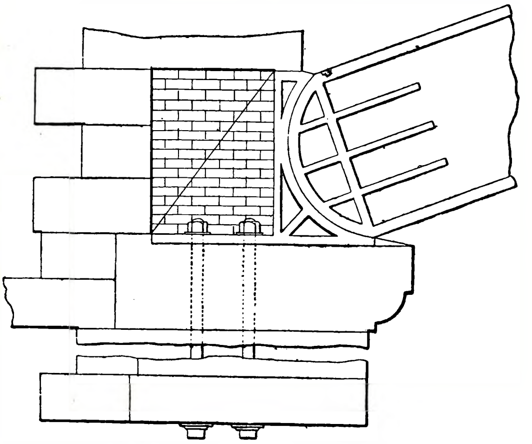
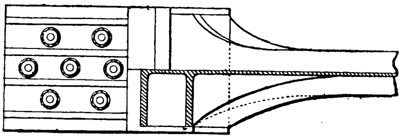


It is to this complete system of bracing throughout the structure that the bridge owes its lateral stiffness, the width being so small as compared with the length, that the greatest care was necessary in designing this part of the work. Upon the roadway girders, balks of timber 13 in. square, are laid and bolted to the top flange at frequent intervals. Into these longitudinal timbers, cross beams of similar scantling and 4 ft. apart are tenoned in the method shown, Figs. 602 and 603, and upon them a close planked flooring, 3 in. thick, is spiked. The ballast which is laid over the platform to a depth of 9 in., is prevented from falling over the sides of the bridge by cast-iron facias 12 in. high, and panelled on the outside, which run the whole length of the bridge. On these facias the handrailing is secured. Short pipes, 3 in. in diameter and about 6 in. long, are passed through the flooring, and carry off such drainage as may accumulate on the ballast. These pipes are placed in three rows, transversely, and at intervals of about 20 ft. Before erection, all the girders were tested, and each segment of the main ribs was proved separately on the concave as well as the convex side, a load of about 70 tons being applied to the centre of each without causing them to show any permanent set, and only a deflection of about 0·08 in.

598.





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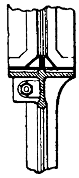

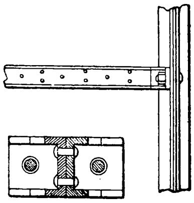

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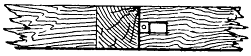

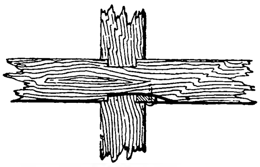

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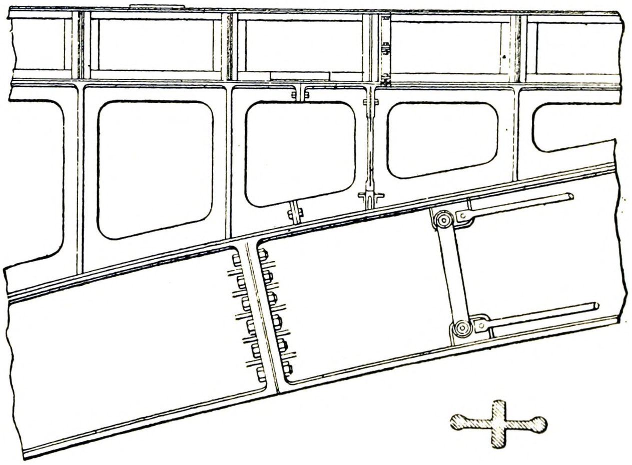


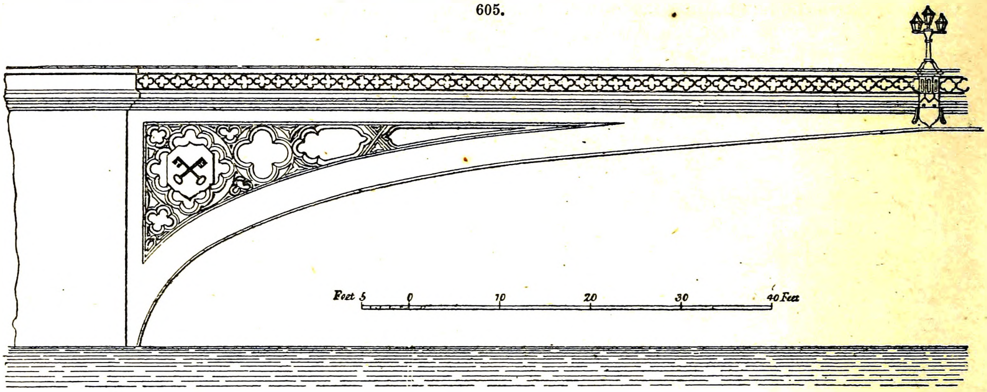
Some of these pieces, which were slightly defective castings, were broken under a central load of 430 tons. As before stated, the bridge, though always in motion from the influence of expansion or contraction, never turns in the least degree on the rounded heels at the springing of each rib, but rises and falls by virtue of its own elasticity. During the course of erection, the arched ribs have been known on a day to lift themselves clear of the scaffolding for a height of 1½ in.

The following is a detailed description of the quantities and material employed;—

Concrete	3344 cubic yards
Brickwork	2578 „ „
Stone for bed-plates, coping pieces, &c.	1780 cubic feet
Timber in sheet piling	1938 „ „
Creosoted fir in beams and flooring	3400 „ „
The total weight of cast iron	348 tons

Before the opening of the railway for public traffic, the bridge was tested with a moving load on each pair of rails, consisting of an engine and tender weighing 45 tons. The greatest deflection was $\frac{1}{2}$ in. The comparatively great amount of material required in the abutment of an arch bridge will be apparent on referring to Fig. 590.

605.



Cast-iron Arch Bridge at York.—This bridge consists of a Tudor arch of cast iron, 175 ft. span, 25 ft. rise, shown in Figs. 605 and 606, in half-elevation and longitudinal section, Figs. 609 to 618 being of details. Fig. 607, a transverse section at the centre. Fig. 608, a transverse section of bridge at 0.0, on internal rib. Fig. 617, section at *b*; Fig. 616, section at *d*. The spandrils are fitted with open Gothic tracery, the principal openings being charged with shields bearing the arms of the see of York. The interior spandrils are fitted with an iron plate, pierced to correspond in pattern with the external Gothic spandrils. The parapet, Fig. 609, consists of quatrefoil openings. The springing-line of the bridge is at the ordinary summer level of the river. The six longitudinal ribs are entirely of cast iron, and are 3 ft. deep at the crown, increasing towards the abutments. These ribs are stiffened by cross beams, varying in depth from 2 ft. 10 in. at the crown to 3 ft. 9 in. as they approach the abutments. A bed is cut in the brickwork for the

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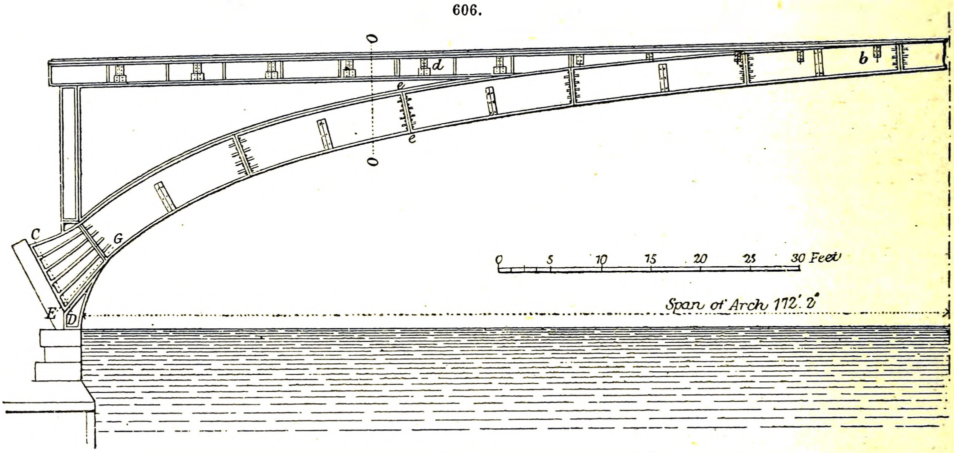

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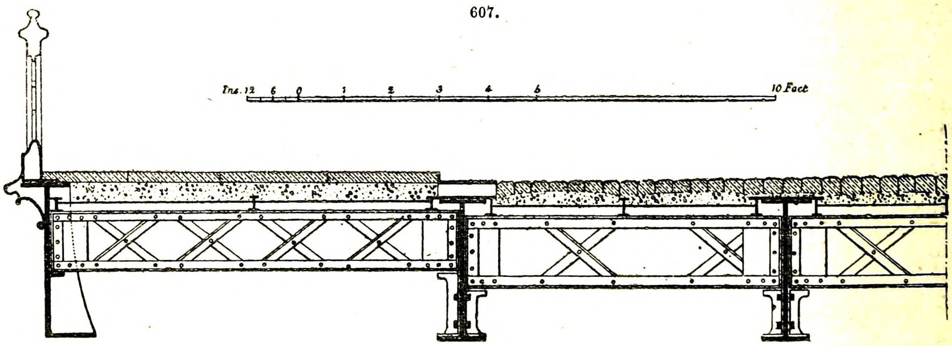
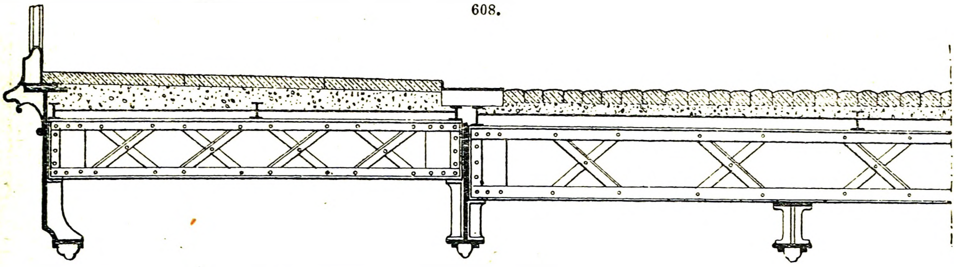


reception of the skewbacks against which the ribs abut, the skewbacks resting upon granite slabs 18 in. thick.

A covering of corrugated plates rests upon the bottom flange of rolled iron joists, placed longitudinally upon the transverse girders. The corrugated plates for the carriage-way are $\frac{3}{8}$ in. thick, and for the footway $\frac{1}{4}$ in. thick.

608.

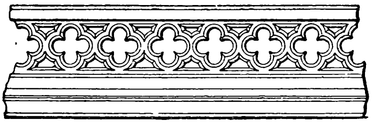


The carriage-way is formed of a layer of concrete 3 in. thick, consisting of cork and bitumen, placed immediately upon the corrugated plates; upon this is a layer of concrete, formed of Portland cement and gravel; and upon the latter is placed the granite paving. The footpaths consist of a layer of concrete 6 in. thick, covered with 3-in. York paving.

The estimated quantities for the bridge were;—

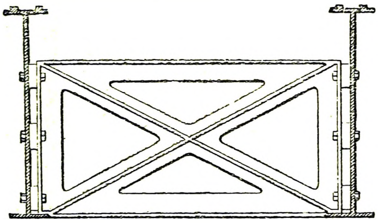
	tons.	cwt.	qrs.
Cast iron	239	0	0
Wrought iron	69	1	1
	308	1	1
Roadway	224	15	0
	532	16	1

609.



Instead of the extremities of the cast-iron ribs of this bridge being free to move, as in the case of that last described, they abut against a cast-iron skewback, Figs. 606, 614, and 615, the two latter figures being sections at E G and C D respectively, and are bolted to it. A similar arrangement occurs in the compound ribs of Westminster Bridge. The increase in depth of the ribs of London Bridge, from the crown towards the springings, is to be particularly noticed, as it adds very much to the graceful appearance of the arch. The sections of the ribs are given in Figs. 610 to 613, which show also the short cast-iron girder which braces together the arched ribs transversely to the interior flanges of which they are bolted.

610.



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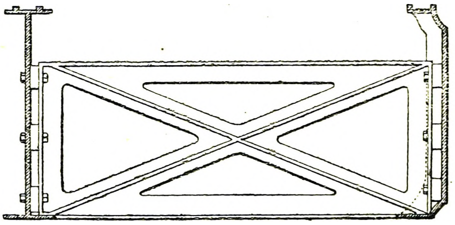

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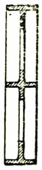

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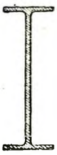

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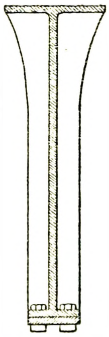

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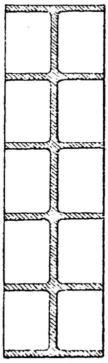

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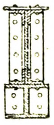

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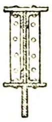

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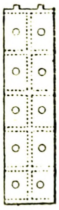
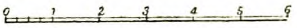
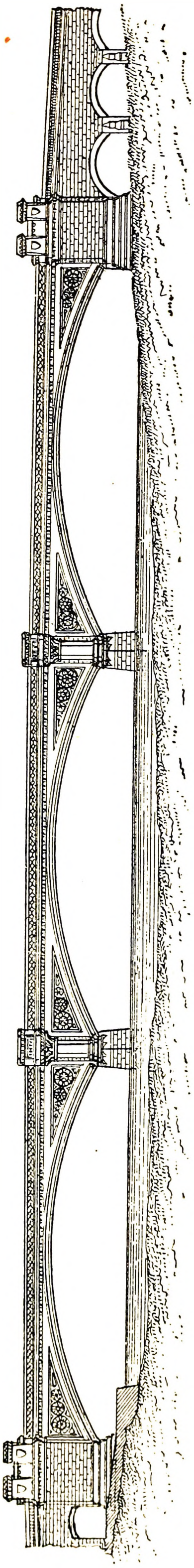




Bridge over the Trent at Nottingham.—This bridge, Figs. 619 to 629, was designed by M. O. Tarbotton. In the vicinity of Nottingham the volume of the river Trent is both large and inconstant. The rainfall is quickly brought down from the higher districts into the main river. The water has been frequently observed to rise at the old bridge as much as 2 ft. within eight or ten hours after the fall of half an inch of rain. The surface of low summer water at the Trent bridge is 65 ft. 8 in. above mean or half-tide level at Hull. Mean summer water may be considered about 1 ft. higher than this, and the mean yearly summer level is about 68 ft. 8 in. above mean tide.

The surface of the road over the bridge is level from end to end, and is about 3 ft. higher



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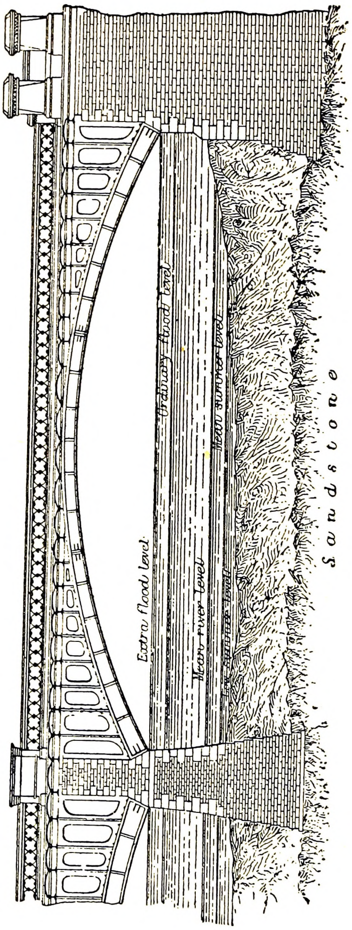
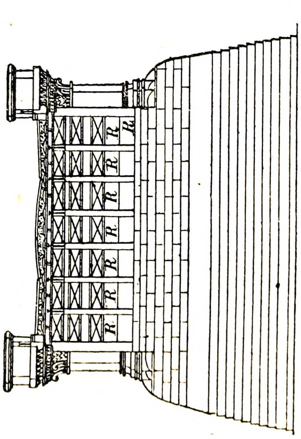

Extra flood level
Ordinary flood level
Mean river level
Mean summer level
Sandstone

621.



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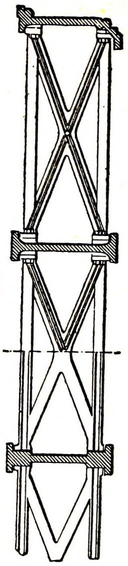

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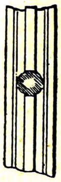

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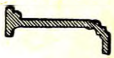

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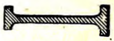

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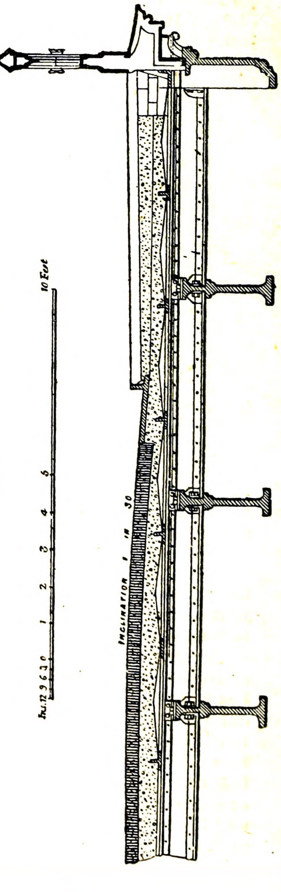
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5
4
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INCLINATION 1 IN 30

622.

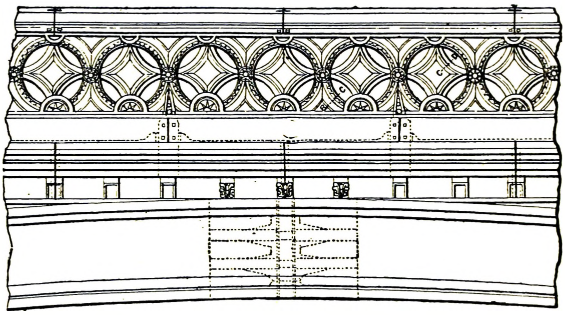
than the highest part of the former bridge road, this being necessary in consequence of the requirements of the navigation, and also by the rise of the large arches of the bridge.

The bridge crosses the river at right angles to the mean course of the stream, the waterway being by three openings, each 100 ft. span. On the north side is an opening, 10 ft. in width, for the hauling-path during floods, and on the south side are three flood arches, 18 ft., 15 ft., and 12 ft. wide respectively.

The foundations are carried into the rock, and the abutments and piers below the lowest water-mark, are of brickwork in cement. The exposed surfaces of the abutments and piers are of rock-faced Derbyshire grit, the ornamental parts being of red sandstone, magnesian limestone, and granite. The footpaths are of Yorkshire landings, and bitumenized concrete and broken stone for the carriage-road, and cast-iron gutters. The parapet is of cast iron, open and ornamental; the recesses and seats over the piers are of stone. The capitals of the clustered columns of the piers are carved elaborately, and the spandrils of the outside ribs are filled in with geometric open work. The ornamental portions are gilded and painted in relief, so as to give effect to the body colour of the rest of the bridge, which is painted a quiet shade. The width of the bridge clear of the parapets is 40 ft., containing footpaths 8 ft. 6 in. wide, and a roadway capable of accommodating three lines of carriages.

This bridge has three spans, each of 100 ft. in the clear, making, with the stone arches of the approaches on either side, a total length of 700 ft., as in Fig. 619. The roadway of the bridge is level, and stands 27 ft. above the summer level of the river, with a clear width between the parapets of 40 ft. The carriage-way is 26 ft. wide, and there are two footpaths, each of 7 ft. The north, or Nottingham approach, has a gradient of 1 in 47, and the south approach 1 in 34. The material of the large main arches is cast iron, and each arch has eight ribs or girders R R, Fig. 620, 3 ft. deep at the springing, and 2 ft. 6 in. deep at the crown, Fig. 621, the mean section being of an I form, 2 ft. 9 in. deep, with top and bottom flanges measuring 7 in. by $1\frac{7}{8}$ in. and 9 in. by 2 in. respectively, as in Fig. 624. The form of section of the face ribs and that of the ordinary ribs is shown in Figs. 624 and 625; and these ribs have bolted to them transverse wrought-iron girders, which carry the roadway platform; the latter is formed of wrought-iron curved plates and Mallett's buckled plates, riveted together with T and L iron stiffeners, shown in cross section in Figs. 622 and 629. Every arch has strong bracing frames, Fig. 623, to connect the several ribs together, and all the joints of the ironwork are planed true, and connected with iron pins or bolts, which were previously turned smooth in a lathe, and fitted into holes drilled, when fixed in place, through the ironwork. The face ribs, Figs. 619 and 627, are of an ornamental character, and are moulded on the lower edges and on the upper lines of the arches. The spandrils are recessed and moulded, and contain medallions of cast iron, fitted within geometrical cuspings enclosed in moulded circles or tracery. The designs for the enrichments vary in each compartment, both in size and detail. Over the arches and spandrils an ornamental moulded cornice of cast iron runs from pier to pier. The whole is surmounted by the parapet Fig. 627, which is of geometric and continuous design, formed of cast-iron open work, with pateras or flowers at the intersections of the curved lines.

627.



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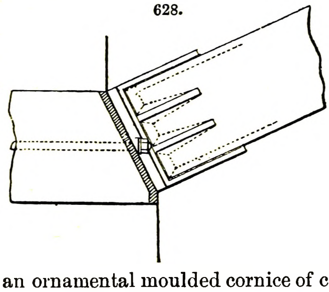

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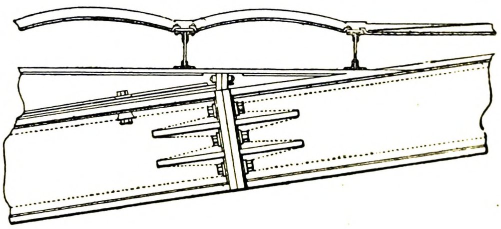


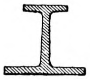
The carriage roadway of the bridge, Fig. 622, is formed, first, of a layer of bituminous concrete, to protect the iron plates from oxidation; then of a foundation of Portland cement concrete, and of a layer of Val de Travers asphalte. The bridge is made strong enough to carry the very heaviest traffic, as will be seen from the following description of the trial loads;—The calculated strain upon the ribs in the centre was 1·4 ton, when the bridge was loaded with a distributed weight of 2 cwt. a square foot over the surface of the bridge. Then, taking the greatest moving load at 2 cwt. a square foot, the gross weight of and upon each arch would be 850 tons. It is difficult to see how 2 cwt. of live load could be put on the bridge, except by treating each pair of ribs as a line of railway, and placing locomotive engines thereon. There would then be eight engines on each arch, equal to 400 tons = 2 cwt. a square foot. In the test the surface was crowded with carts filled with granite, and passed along at all speeds without sensible deflection or much vibration. The weight of the ironwork in the bridge is as under;—

	tons.
Cast iron—	
Main inside ribs	254
Spandrils for ditto	104
Face ribs	$160\frac{1}{2}$
Ornaments in face ribs	5
Cornice, coping, and parapet	$112\frac{1}{2}$
Bracing and other cast iron	$60\frac{1}{4}$
Wrought iron	173
	$869\frac{1}{4}$

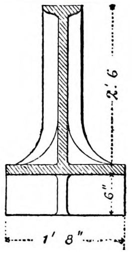
The above weights do not include the railing on the approaches or the lamp pillars.

Cast-iron Flanged Girders.—The form of girder in almost universal use since the researches of Hodgkinson is the flanged type, Fig. 630, of which the girder used in the covered way of the Metropolitan Railway, represented in section and part elevation Figs. 631, 632, is a specimen.

630.



631.



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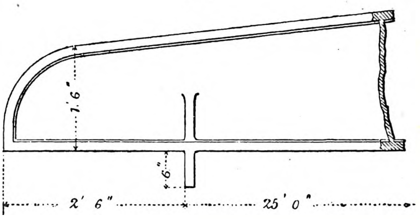
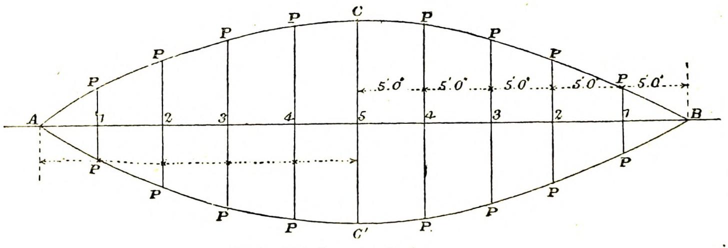


One great practical inconvenience attaching to the use of cast-iron girders is the necessity of testing each girder in order to detect the existence of dangerous flaws. The girders, Figs. 631, 632, were tested in pairs by hydraulic pressure; and with a stress equivalent to a load of 45 tons applied at the centre the average deflection was $\frac{5}{8}$ in. By the ordinary formula $\text{B.W.} = \frac{4\,\text{D}fa}{\text{S}}$, the breaking weight at the centre, with an estimated ultimate tensile resistance of 7 tons a sq. in., would be

$$\text{B.W.} = \frac{4\text{ ft.} \times 2\text{ ft. }6\text{ in.} \times 7\text{ tons} \times 42\cdot5\text{ sq. in.}}{25\text{ ft.}} = 119\text{ tons.}$$

The horizontal strain upon any point of a girder, uniformly loaded with a distributed weight, will vary as the rectangle under the segments into which the point divides the span of the girder, and consequently the breadth of the bottom flange, if the girder be of uniform depth, or the depth of the girder, if the flange be of uniform width, must vary in this proportion to attain uniform strength. If the girder therefore be divided into segments and along its whole length, the breadth at any one point should be to that at any other point as the product of the four different segments, taken two by two. In Fig. 633 is represented a plan of a girder designed to carry a uniformly distributed

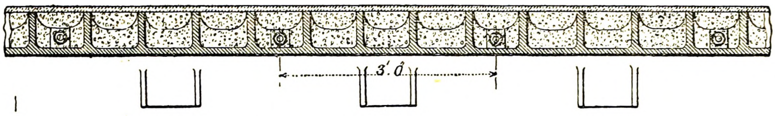
633.

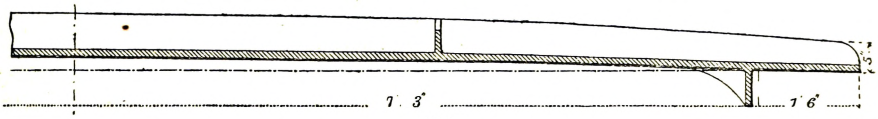


Scale 120 Tons to 1 Inch

load, the span being 50 ft. and the load 1 ton a running foot. At every 5 ft. at the points 1, 2, 3, 4, and 5, the strains may be calculated from the rules given, and will be found to be 22·5, 40, 52·5, 60, and 62·5 tons respectively. Upon any given scale, plot off these strains, or any subdivisions of them, upon lines drawn perpendicular to the axis A B of the girder, through the points 1, 2, 3, &c. Join all the points P, thus determined, with a French curve, until the whole figure A C B C′ A is produced. If this figure is accurately drawn, it will be found to consist of two parabolas, demonstrating that the strain upon any point of the flanges of the girder, produced by a uniformly distributed load, varies as the ordinates of a parabola. This is the true form of a bow and string girder, although in actual practice, an arc of a circle is always substituted for the more complicated parabolic outline. When the headway is very limited, cast-iron troughs are not unfrequently used. Figs. 634, 635, show those used on the St. John's Wood Railway, where a thickness of 9 in. only was available from the under side of girder to the surface of the road. At a span of 16 ft. the deflection of the 3 ft. wide troughs was barely ⅝ in., under a load of 10 tons at the centre.

634.





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Breaking Weight and Working Load of Cast-iron Girders.—The Commissioners appointed to inquire into the use of cast and wrought iron for railway purposes, considered one-sixth of the breaking weight scarcely a sufficient limit of safety for cast-iron girders, when liable to percussion and deflection from moving loads. This inference was, no doubt, influenced by their experiments on bars which were much lighter in proportion to their loads than are ordinary bridge girders. As a general rule, one-sixth of the breaking strain may be taken as the safe working strain, for cast-iron girders which are liable to vibration; but when the load is stationary and free from all vibration, one-fourth of the breaking strain is safe. When, however, cast-iron girders are liable to sudden severe shocks, as in crane-posts or machinery, their working strain should not exceed one-eighth of their breaking strain.

The English Board of Trade has laid down the following rule for the guidance of engineers in the construction of railway bridges;—"In a cast-iron bridge the breaking weight of the girders should be not less than three times the permanent load due to the weight of the superstructure, added to six times the greatest moving load that can be brought upon it." Notwithstanding this rule, engineers will do well not to design cast-iron girders for railway bridges of less strength than six times the total maximum load, that is, six times the permanent load added to six times the greatest moving load. The reader who desires detailed information respecting the practice of our most eminent engineers during the reign of cast iron, is referred to the evidence attached to the "Report of the Commissioners appointed to inquire into the application of iron to railway structures," in 1849. It seems certain that the transverse strength of thick, rectangular cast-iron bars is less than that of thin ones, but it does not necessarily follow that the strength of large flanged girders is diminished by the massiveness of the casting, or that they are relatively weaker than smaller girders of similar section; for the quality of the iron will no doubt materially influence their strength. Experiments on a large scale can only decide these questions, which, however, have less importance now than in 1849, as it is very unlikely that large cast-iron girders will be employed in important works when wrought iron is available. Cast iron can be readily obtained to stand from 7½ to 9 tons a square inch in tension; consequently, the rule of one-sixth allows an inch strain of from 1¼ to 1½ ton, for the usual safe tensile working strain in the lower flanges of cast-iron girders, but this material is quite unfitted for tie-bars. Cast iron will safely bear 6 or 7 tons a square inch in compression, provided it is in a form to resist flexure; but the effects of flexure will seriously diminish the safe unit strain for pillars or unbraced cast-iron arches, in which the line of pressure may vary so as to alter the calculated unit strain very materially. In practice, the safe working strain of cast-iron arches rarely exceeds 3 tons a square inch. For instance, the calculated working strain in the Severn Valley bridge is between 2½ and 3 tons a square inch, while that of the centre arch of Southwark Bridge is about 2 tons a square inch. The French ministerial limit of working strain for cast iron in tension is one kilogramme a square millimetre = 0·635 ton a square inch, and in compression five kilogrammes a square millimetre = 3·175 tons a square inch. The direct tensile strength of cast iron can be readily tested, but it is also usual to prove its transverse strength by breaking small rectangular bars made of the same metal, and at the same time as the principal castings. The following tests are an example, and were applied in the case of the cast-iron sleepers provided for the Great Indian Peninsular Railway;—

The mixture of metal to be such as would produce the strongest and toughest castings, and to be approved by the consulting engineer. The contractor to cast twice each day, from the same metal as that used in the sleepers, two duplicate bars 3 ft. 6 in. × 2 in. × 1 in., and two duplicate castings of the form shown on the contract drawing, and exactly 1 in. square for a length of 1½ in. in the middle. One of the bars to be tested on edge, on bearings 3 ft. apart, by placing weights on the centre thereof, to ascertain its elasticity and breaking weight, and one of the two castings to be tested in a suitable machine, of approved construction, to ascertain the tensile strength of the iron.

The company's inspector to reject all sleepers cast on any day when each of the bars does not bear 30 cwt. placed on the centre without breaking, or when each bar does not deflect 0·29 of an inch before fracture, and when each casting does not bear a tensional strain of 11½ tons per square inch of section. Three sleepers also to be tested each day by a weight of 3¾ cwt. falling through 5 ft. 6 in., the same having previously been subjected to blows from the weight falling through 2 ft., 2 ft. 6 in., 3 ft., 3 ft. 6 in., 4 ft., 4 ft. 6 in., and 5 ft. successively, after the sand foundation, not to be more than 24 in. thick under the centre of the sleeper, and laid on a cast-iron bed-plate 8 in. thick, and weighing 2 tons, has been well consolidated to the satisfaction of the consulting engineer or his inspector; and whenever every sleeper so tested does not bear these blows, without cracking or showing other signs of failure, the day's make to be rejected. Immediately after every sleeper is cast, it must be protected in such a manner as to satisfy the company's engineer, and the process of cooling to proceed so slowly that its strength will not in any degree be diminished by too rapid or unequal cooling.

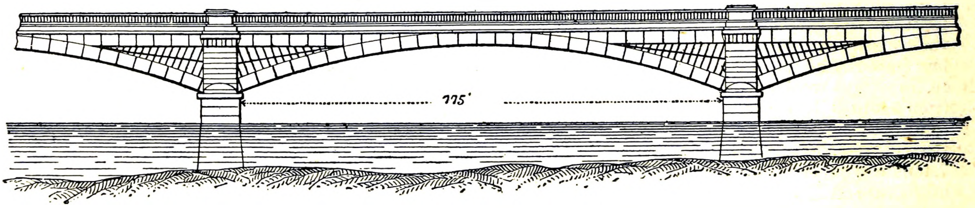
Some engineers consider this proof rather high, and specify that test bars 2 × 1 in., placed edgeways on bearings 3 ft. apart, shall support a weight on the centre of 25 cwt. It appears that sleepers can be obtained that will withstand blows better, without using so high a bar test. It is a singular fact, that there is an excess of about 16 per cent. in the weight that a test bar 2 in. × 1 in. will support, when cast on edge and proved as cast, over that which it will support with the under side as cast placed at the top when proved, and 8 per cent. over the weight which the same test bar will support, if cast on its side or end and proved on edge. The practical deduction from this fact is, that cast-iron girders should be cast with the tension flange downwards in the sand.

Wrought-iron Bridges.—We shall exclude from our category of wrought-iron bridges the tubular and the box types. The former is quite obsolete, and in fact presents but three examples. These are the Britannia Bridge over the Menai Straits, the Victoria Bridge over the St. Lawrence at Montreal, and a similar structure of the same name over a river in Australia. The box girder is also out of date for large structures, and is used chiefly for supporting the walls of large warehouses and stores.

Wrought-iron Arches.—The theoretical rules laid down for the strains upon cast-iron arches apply to those of wrought iron or of any metal. We may therefore pass on to the practical examples of this description of bridge. Many engineers prefer the wrought-iron to the cast-iron arch, in instances in which the moving load greatly exceeds the dead weight of the structure, and is also of a very concussive character.

Victoria Bridge, Battersea.—This bridge, although in one sense a widening of an existing structure, in reality constitutes a separate bridge, as the supports for the load are constructed upon distinct principles, and it rests on a different kind of foundation. The ironwork of the new bridge is unconnected with the old; but the masonry in the piers and abutments is bonded together, and the facework of the old piers having been taken down is re-erected on the piers of the new bridge. The spans are identical with those in the old bridge, namely, four arches of 175 ft. over the waterway, besides one span of 70 ft. and one of 65 ft. on either bank of the river. One arch is shown in Fig. 636. The rise of the arches is the same as in the other bridge, but in the new structure the horizontal girder, running the whole length from end to end, is deeper, and none of the rivets in the facework are countersunk. The two bridges together may, however, be considered as one railway bridge, the widest in the world, possessing as it does a total width of 132 ft. from parapet to parapet, and accommodating seven lines of railway, still leaving a width of 33 ft. 6 in. available for platforms.

636.



Although resembling each other in appearance, there is a radical difference in the principles upon which the old and new bridges have been constructed. In one an expansion joint exists in the horizontal girders over each of the piers; in the other this girder is continuous throughout. In the first case the rib is simply a wrought-iron arch; in the latter it is to some extent the lower member of a continuous girder. In the old bridge the width of the piers at the foundations is considerably extended, probably to meet the effect of the unequal thrust on the arched ribs caused by passing loads. In the new bridge the weight acts more vertically on the piers, which are founded upon cast-iron cylinders. These cylinders, of which there are four to each pier, are 21 ft. in diameter, 1¼ in. thick, filled with concrete up to the level of the river bed, and above that with brickwork in cement to a little below low-water mark. At this level the masonry of the cylinders is connected by arching, and is faced with Roche Portland stone, similar to that in the old bridge. The cylinders were sunk with great facility.

The ribs R, Fig. 637, rest on cast-iron skewbacks, Figs. 638 to 640, which pass entirely through the piers; standards resting on the skewbacks support the horizontal girder at top, as shown in Fig. 639, to which they are securely bolted. The whole bridge from end to end being one connected mass of ironwork, thoroughly braced horizontally and vertically, and the whole being riveted together at an average medium temperature, it is estimated that the extreme effect of change in the temperature would be, to put an initial strain of 4 tons a square inch, either of compression or tension, on the iron. This liability to unusually great strains from changes of temperature, together with the uncertainty generally as to the strains occurring on the ironwork, render the widened portion of the Victoria Bridge a type of construction essentially unscientific, and therefore to be avoided rather than imitated. The two land spans are formed of continuous girders, the shorter ends of each being anchored down, by a vertical plate passing down to the springing of the adjacent rib. The cross girders are the Butterley Company's 12-in. rolled beams, about 6 ft. apart, and the longitudinal bearers supporting the rail are 9-in. beams of the same manufacture.

In the construction of this bridge there have been used 8200 cubic yards of concrete, 13,800 cubic yards of brickwork, 90,000 cubic feet of masonry, 760 tons of cast iron, 3600 tons of wrought iron, 284,000 cubic feet of timber in the temporary staging, and 40,000 cubic feet of timber in the platforms. The bridge was tested by the Government Inspector, with eight of the heaviest of the London, Chatham, and Dover Company's engines. The greatest deflection noted on the loaded rib was $\frac{7}{8}$ of an inch; there was at the same time a rise of $\frac{1}{8}$ of an inch on the corresponding rib in each of the adjacent spans. The deflection of the girder over the land span was $\frac{3}{8}$ of an inch under the same test. At the time the older bridge was built, the use of cast-iron cylinders in putting in subaqueous foundations was not so well understood, at least on the Thames, as it is now; and it will be seen that the projecting toe of the foundations of the piers of the old bridge was protected by sheet piling, which it was not considered advisable to remove. This involved some difficulty, and it was finally decided to put in the foundations for the new bridge as perfectly distinct structures, to be subsequently bonded to the old work. Circular caissons, of the dimensions given above, were therefore put in, and sunk as close as possible to the sheet piling. The mode of sinking these cylinders possesses some novelty. Instead of heaping kentledge on top, as is usually done, platforms were constructed and slung within the cylinders, and these were loaded as was necessary. After the new pier had been carried up to a sufficient height, it was connected with the old by masonry, protected by cast-iron aprons, in the place of an old and new pier, the aprons being so cut and painted as to resemble ashlar work. Much ingenuity has been displayed in working out the details of this design.

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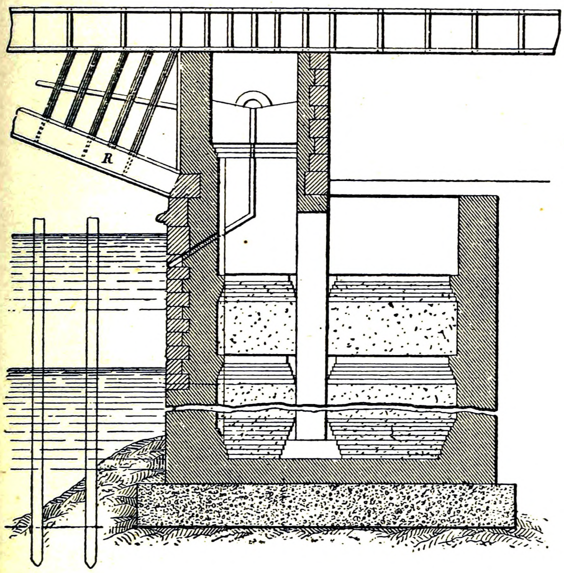

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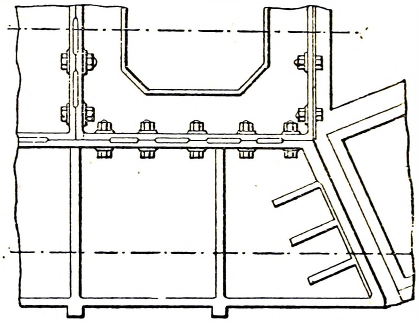

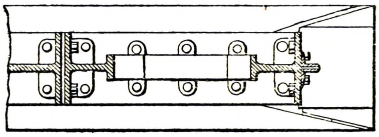

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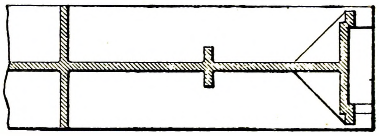

Blackfriars Bridge.—This is one of the largest examples of the application of wrought-iron arches to public road bridges. Its spans are much larger than those of Westminster Bridge, which is in fact a combination of cast and wrought iron, since the central portion of each rib is quite flat, and composed of a wrought-iron girder, while the haunches and springings are of cast iron. There are five arches in Blackfriars Bridge, the longitudinal section of half the central arch having a span of 185 ft., as in Fig. 641.

The spans of the openings are, in the side or abutment arches, 155 ft.; in the two next, 175 ft., and in the centre one 185 ft. The versed sines or rises of the arches from springings to soffits are in the side arches 11 ft. 7½ in.; in the two intermediate arches, 13 ft. 10½ in., and in the centre arch 15 ft. 11¾ in. The soffit of the last is 25 ft. above Trinity high-water mark, and the others in proportion. There are nine main ribs in each arch, placed at a distance of 9 ft. 6½ in. from centre to centre and tied together with strong diagonal bracing, riveted to them longitudinally and transversely, as shown in Fig. 642. Across the arches, from rib to rib, are placed the roadway bearers, or small girders, and on the top of these, over the whole area of the bridge, buckled plates are riveted, so as to form a decking, or flooring, for the roadways and pathways to rest upon. The dimensions of the plates vary considerably, and are as follows;—4 ft. 5 in. by 3 ft. 6 in. by $\frac{3}{16}$ in., 4 ft. 9 in. by 3 ft. 6 in. by $\frac{3}{8}$ in., 4 ft. 9 in. by 3 ft. 6 in. by $\frac{5}{16}$ in., 5 ft. 6 in. by 3 ft. by $\frac{5}{16}$ in., and 5 ft. 6 in. by 4 ft. 9 in. by $\frac{5}{16}$ in. The thinner plates are placed under the pathways, and the thicker ones under the roadway, Figs. 642 and 643. Fig. 644 is a cross section of the face girder, showing the manner in which the parapet and circular mouldings are fixed. In the majority of instances arched ribs, whether of wrought or cast iron, are made of uniform depth and uniform section. Theoretically, the arched rib should be strongest at the springing, not, as is too frequently assumed, on account of the increased thrust at that point, but on account of the increased bending moment due to changes of temperature, rolling load, and otherwise. In some instances, such as the St. Louis bridge, to be hereafter referred to, the arched rib is reinforced in section for a short distance from the springing. In others the rib is pivoted at the springing, whereby of course the bending stresses are eliminated, and the section required at the springing is smaller than at any other part of the rib.

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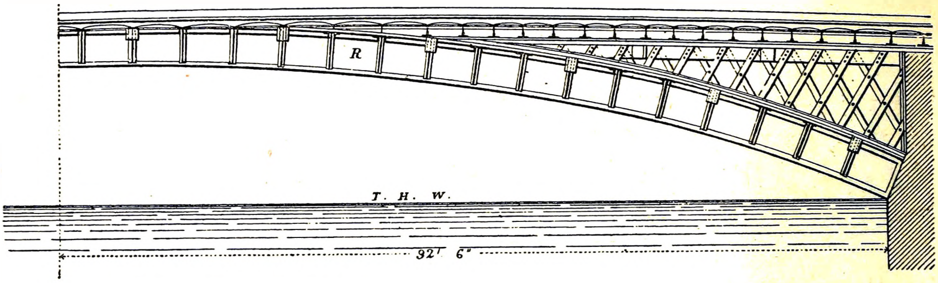

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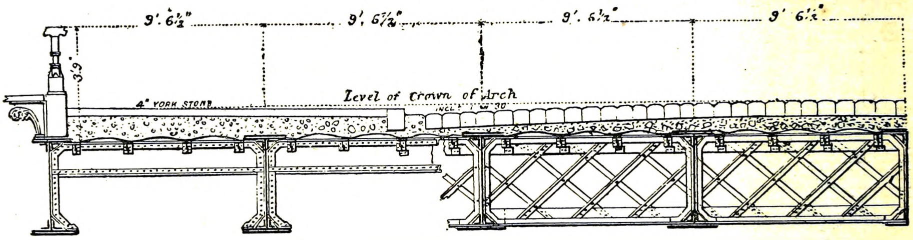

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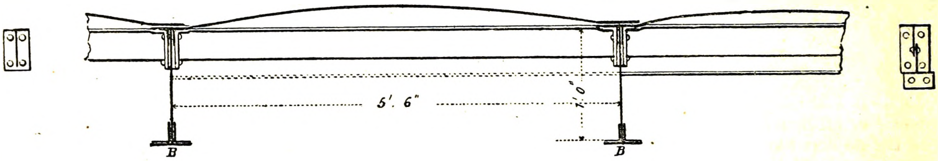
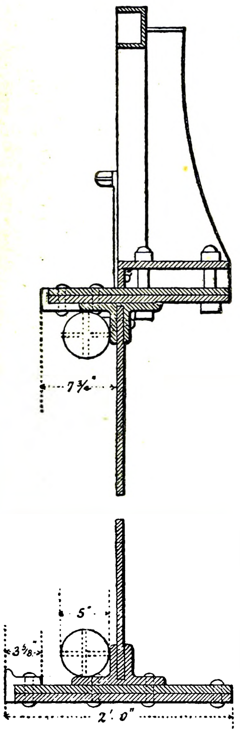


Plate Girders.—The single-web plate girder, previously to the introduction and adoption of the open-web or lattice type, was a favourite form of construction, and is still much used. When, however, the span exceeds 70 ft., the open web will in general be found the more economical of the two. The strains upon the flanges of plate girders can be calculated by the rules already given for those in cast iron.

Strains upon the Web of Plate Girders.—The strains upon the web of a plate-girder are transferred in a diagonal direction, but for the purposes of calculation, they are assumed to consist simply of a vertical shearing strain, tending to shear the web right through. Two general cases will present themselves with respect to the strains upon the web; one in which they result from a uniformly distributed or dead load, and the other from a variable, or rolling weight, frequently called, in contradistinction to the other, a live load. The shearing strain at any point of a uniformly loaded girder, is equal to the total weight situated between that point and the centre of the girder. In Fig. 645, which represents the skeleton elevation of a wrought-iron plate girder, the strain upon the web at any part E F, will therefore be equal to the total weight distributed over the distance Y, extending from that point to A B, the centre of the girder. Consequently, if the load a foot run, uniformly distributed over the girder, be 1 ton, and Y be equal to 10 ft., the shearing strain at E F will be equal to 10 tons. As the weights with their resulting strains, are transmitted ultimately to the abutments through the means of the web, the shearing strains at those points will be greater than anywhere else, and will equal, as has been previously mentioned, half the total weight distributed over the girder. In all straight girders, similar to that represented in Fig. 645, where the upper and lower flanges are horizontal and parallel, the strains in the web are proportional to the distance Y, but if either of the flanges should be curved, as in a bowstring girder, they no longer obey this law, the curving of either the upper or the lower flange very considerably modifying the amount and position of the strains, since a portion or the whole of the shearing strains may then be sustained by the flanges.

The investigation of the next case is apparently more complicated. Instead of the load being uniformly distributed over the girder, let it be represented by an ordinary railway train, which will successively cover the various portions of the bridge in its passage across. Neglecting the weight of the girder itself, it is evident that, if the rolling load has advanced from the abutment D to the point E F, in Fig. 645, so as to cover the whole of the larger segment of the girder, into which the line E F divides it, there will be no weight upon that portion of the girder situated between E F and the abutment C. Consequently there will be no weight to be subtracted from that at E F in the calculation, and the shearing strain at the point will equal that transmitted to the abutment C. At the centre, with a distributed load, the shearing strain is nothing, but with a rolling load, its value is always one-eighth of that load. The maximum shearing stress at any point will be obtained when the rolling load covers half the bridge and extends beyond the centre to the given point.

644.



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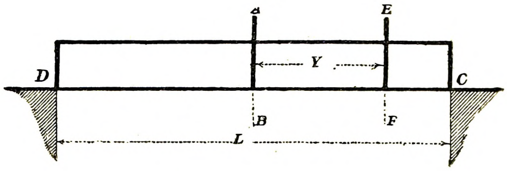

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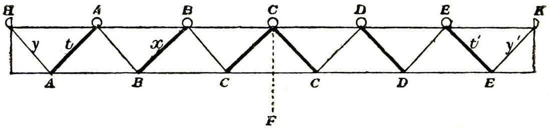


Plate Girders.—A practical example of this description of girder will be found under Bridge in this Dictionary.

Open-Web Girders.—The simplest form of the open-web girder is that known as the Warren, represented in Fig. 646, in which the web consists of one series of triangles. The original Warren girder was a combination of cast-iron struts and wrought-iron ties, but owing to several failures, engineers abandoned the use of cast iron, and employed the latter material only in its construction.

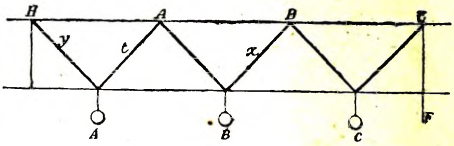
We shall not enter into the relative merits of pins and rivets in connecting the flanges and webs of open-web girders. It will suffice to observe that in the Crumlin Viaduct, which is a well-known example of a Warren girder, the pins failed, owing to their bad proportions, and have been taken out, and rivets and gusset pieces used to make good the junctions of the web and flanges. In American bridges, pin fastenings are almost exclusively used, and no such failures are encountered.

Let Fig. 646 represent a girder, uniformly loaded throughout its length, or, what amounts to the same, suppose the weights collected at the several apices of the triangles. Selecting any bar x, the total strain upon it will be equal to the shearing strain at the apex B, multiplied by the cosecant of the angle of the inclination of the bar to the horizon. The shearing strain will be equal, as already stated, to the sum of the weights situated between the apex and the centre of the girder. If each of the weights A, B, C, be equal to 1 ton, then the total strain upon the bar x equals $1 \cdot 5 \times 1 \cdot 4 = 2 \cdot 10$ tons, assuming the angle of inclination of the bar to be 45°. Let us now proceed to obtain this result by considering the action of each individual weight. Commencing with the weight of 1 ton at E, upon the principle of the lever, five-sixths of it are transferred to the abutment K, and one-sixth to H. The vertical component of the strain brought upon the bar x, by the weight placed at E, is a compression of one-sixth of a ton. Similarly, the vertical component of strain upon x, due to the weight D, will be two-sixths of a ton, that of the weight C three-sixths of a ton, and that of B four-sixths of a ton. All these strains are compressive, and summing up we find the total to be equal to $(\frac{1}{6} + \frac{2}{6} + \frac{3}{6} + \frac{4}{6}) = \frac{10}{6} = 1\frac{4}{6}$ ton. But the bar x is also subject to a tensile strain from the effect of the weight A, which is equal vertically to one-sixth of a ton, so that the total strain upon the bar x is equal $1\frac{4}{6} - \frac{1}{6} = 1\frac{1}{2}$ ton as before. Multiplying this by $1 \cdot 4$, we obtain the result to be as before $2 \cdot 10$ tons.

The tensile strain, brought by the weight at A upon x, is neutralized by the compressive strain resulting from the action of that at E, and the compressive strain coming from the weight at D is of exactly the same amount as that portion of the weight at B, which does not pass down x towards H. The reason why the last bars, or those nearest the abutments, are always strained to a maximum is thus apparent. Since the weights at K and H, which are respectively equal to half those at the apices of the triangles, cause no strain upon the bars y, y', but are supported altogether by the vertical reaction of the abutment, there is no neutralizing strain upon them. The bar y is strained in tension by all the weights A, B, C, D, E, and there is no compressive strain at H to be subtracted from their united action. In the present instance the bars t, t' are also strained to a maximum in compression, being evidently affected by the same weights to the same extent as y and y', but the strain is of a compressive instead of a tensile character. The bars y and t and y' and t' are said to be pairs, that is, they are acted upon by strains of the same amount, but of an opposite nature. From the rules previously laid down, the strain upon t and t' is a compression of half the load upon the apices of the triangle, multiplied by 1·4, and that upon y and y' a tension of the same amount. Both these strains consequently = (2·5 × 1·4) = 3·5 tons. The vertical pressure upon each of the uprights H and K will be equal to half the total load upon the girder, equal to 3 tons.

Having now made clear the manner in which the bars are affected by the several weights, the strains upon the flanges have next to be considered. The strain upon the whole of the upper flange is compressive, and is induced by the bars tending to compress or double it up towards the centre. That upon the lower flange is tensile in character, and its tendency is to stretch the flange from the centre. The strain upon A B is the sum of the horizontal components of the stresses upon the diagonals H A and A A. That upon B C is equal to A B plus the horizontal components of the stresses upon the diagonals A B and B B, and similarly for any number of triangulations. It will be seen hereafter, that the strains upon the upper and lower flanges are not perfectly, although very nearly, equal, and moreover, the actual amount of each will depend in a great measure on the position of the load, whether it be placed at the top or the bottom of the girder. The strains upon the various bars are also affected by the position of the load. Let Fig. 647 represent one-half of Fig. 646, and let the weights be situated as represented in the latter figure, the same letters being used for both. Since it is necessary to consider the action of the weights upon only those bars that are placed between the load and the nearest abutment, there is therefore no strain whatever upon the bar C C, when the weights are situated at the lower apices of the triangles. When they were placed upon the top, the bar C C was subjected to a compressive strain of 0·7 ton, but in the present instance it is free from strain. The reason of this is at once apparent, if we imagine the other weight to be placed at C, upon the other side of the centre line C F, in Fig. 647, as already explained. With a weight of 1 ton at C, the tensile strain upon the bar C B will be 1·4 ton, and a similar compressive strain will be exerted on B B and A A, also a tensile one of the same amount upon B A and A H. These strains are those produced on the bars by the action of the weight at C, which is thus accounted for. The weight placed at B will exert corresponding strains of the same amount upon the bars that are situated between it and the abutment, that is upon B A, A A, and A H. The bar A H will finally receive a third strain due to the action of the weight at A. It is first to be observed that the arrangement amongst the bars is changed by altering the position of the load. Those which were pairs in the former instance are no longer so now. There is also a greater total load upon the girder by the arrangement adopted in Fig. 647.

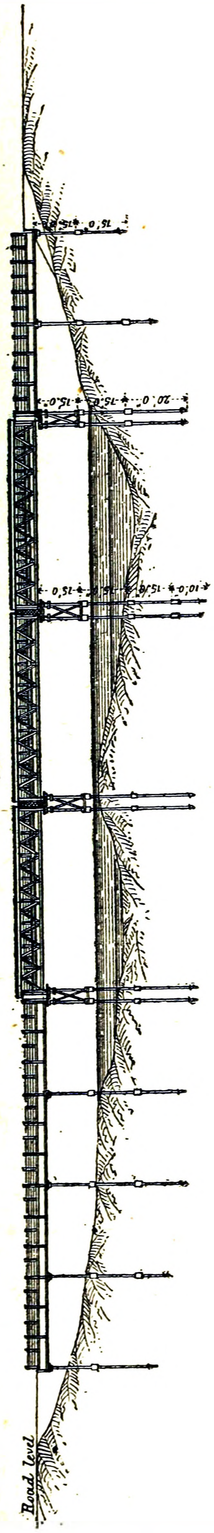
647.



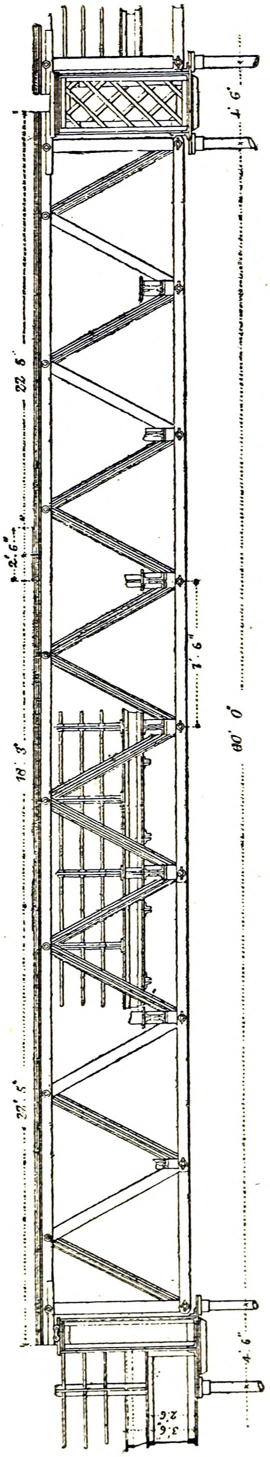
If we take the half-girder in Fig. 646, the whole load upon it is $2\frac{1}{2}$ tons, since half a ton is supported directly by the vertical reaction of the abutment at H, whereas in Fig. 647 the whole 3 tons are supported at the lower points of the triangles, consequently the strain upon the end bar Y will be greater than in the other case. In Fig. 646 it was shown to be equal to 2·5 × 1·4 = 3·5 tons. By the same rule it will now be equal to 3 × 1·2 = 4·2 tons. The difference is evidently the diagonal component of the vertical load of half a ton, which is not carried by the support, and which is equal to 0·5 × 1·4 = 0·7 ton.

Girders with One Series of Triangles.—The Warren girder was the original type of the open-web girders, but the name, although still retained, is not strictly applicable to girders with only a single system of triangulation. In fact, many of the distinguishing features of this description of girder have disappeared. The angle of the bars which divided the whole web into a series of equilateral triangles, is no longer universally adhered to. Rivets are frequently used instead of pins to form the connections, and the employment of cast iron has been abandoned.

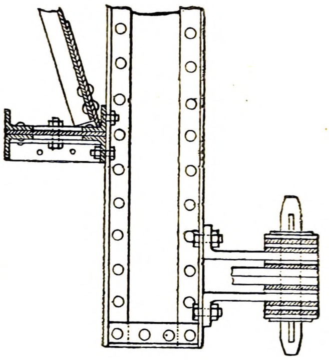
The example shown in elevation in Fig. 648 is that of a road bridge erected over the Ganges. Exclusive of the side spans, which consist of plate girders, the three central spans are carried by wrought-iron Warren girders, having a clear bearing between the centres of the end pins of 60 ft., the most economical span under the circumstances. The bridge is supported on screw piles. An elevation of one girder is shown in Fig. 649. The depth of the girder from centre of pins in the upper and lower flanges respectively is 6 ft. 11 in. The upper or compression flange is of the trough shape, composed of horizontal plates and angle irons of the several lengths Fig. 650, while the lower consists of vertical bars or links $6\frac{1}{2}$ in. in depth, but varying in number and thickness according to their position in the flange, being a maximum in both at the centre, and a minimum at the ends over the bearings. The girders are not continuous over the piers, but are carried upon rollers over the standards. Upon these rollers the upper flange rests, so that the girder is really suspended from the top flange, the vertical tie-bars at the ends of the girders constituting the suspending rods, Fig. 649. This method of support is very similar to that employed in the Crumlin Viaduct. The diagonal struts are made up of T irons and plain bars, while the ties consist of the latter only. All the T irons in the struts have a uniform section of $4\frac{1}{2}$ in. × 3 in. × $\frac{3}{8}$ in., and all the bars are 6 in. × $\frac{1}{2}$ in., with the exception of the end ones, in which the thickness is increased to $\frac{7}{8}$ in. It is to be noticed that the diagonal bars in the web of the four central bays are counterbraced, that is, the ties as well as the struts are composed of both T irons and bars. The diagonal ties in the remainder of the web are made up of plain bars all $6\frac{1}{2}$ in. wide, but varying in thickness from $\frac{9}{16}$ in. to $\frac{11}{16}$ in. The struts and ties at their intersection with the flanges are connected together by pins turned all over, with slotted collar holes. The pins vary in diameter from $2\frac{1}{4}$ in. to $2\frac{1}{2}$ in., and in length from 1 ft. $1\frac{3}{4}$ in. to 1 ft. $7\frac{1}{2}$ in., and pass completely through each flange. A portion of the longitudinal girder which carries the roadway and of the uprights and railing, plain gas tubing $1\frac{1}{2}$ in. in diameter, is shown in the elevation of the girder in Fig. 649. In Fig. 650 is represented a transverse section of the bridge. The roadway is carried on bent corrugated iron plates, having a 2-in. lap at the sides and a 9-in. lap at the ends. The sides are single bolted and the ends treble bolted. The bolts are $\frac{5}{8}$ in. diameter with a 4-in. pitch.


15.0
15.0
20.0
15.0
15.0
15.0
15.0
15.0
10.0
Road level

648.


4' 6"
22' 8"
2' 6"
1' 6"
18' 3"
60' 0"
22' 5"
4' 6"
3' 6"
2' 6"

649.



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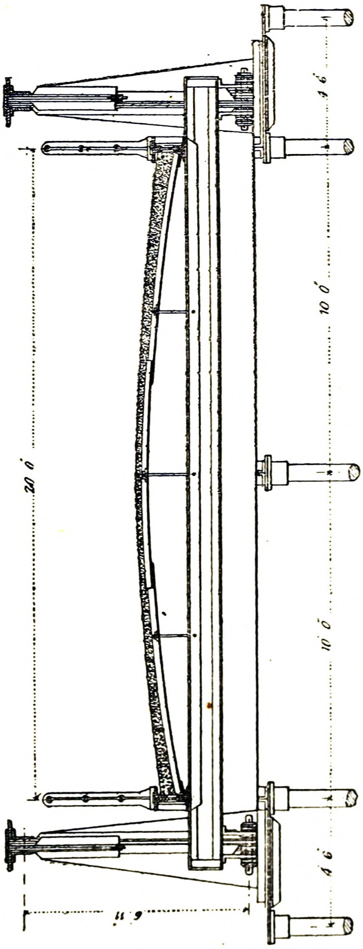
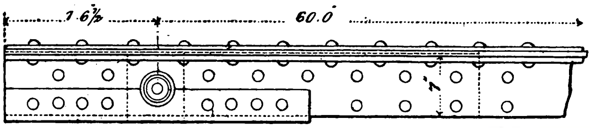

4' 6"
10' 0"
20' 0"
10' 0"
4' 6"
11' 9"

650.

The manner in which the wrought-iron plate cross-girders, the longitudinal, or side girders, and the corrugated iron plates are secured together, is shown in detail in Fig. 651. This type of floor plates is unusual and not to be recommended for general adoption.

The ends of the cross girders rest upon a couple of brackets 6½ in. × ⅞ in., which are in form angle irons, with one long and one short side. The shorter sides have holes drilled in them to take turned bolts, while the longer have similar holes of larger diameter, through which the pins pass to connect the diagonal bars in the web with the flanges. There is some riveting in the top flange, although pins are used for the attachment of the diagonal bars, and riveting is also required in the cross girders and general erection. An elevation of the end of the upper flange is shown in Fig. 652, and a section of the same in Fig. 653. The section is rather peculiar, inasmuch as the horizontal plates are not carried continuously through the entire breadth of the flange, but consist of two half-plates, as they might be called, and are riveted to the angle irons. Figs. 654 and 655 represent an elevation and plan of the joints in the upper flange. The angle irons are of a heavy section, 7 in. × 3 in. × ½ in. The great disproportionate length of one side is due to the necessity for providing sufficient bearing area for the pins, which, owing to their greater diameter as compared with rivets, occasion a heavy loss of material. The pins are placed at the centre of the angle irons instead of at the centre of gravity of the cross section of the top flange, a mistake very commonly made, though it entails an increased strain of from 20 to 50 per cent., according to the amount of the error. Figs. 656 to 659 are of the details of the rollers, which are placed over the supports at one end of each girder, the other end of the girder being fixed.

652.



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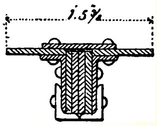

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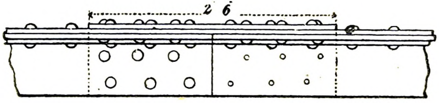

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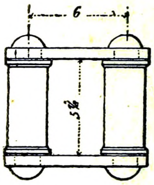

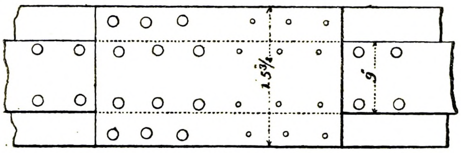

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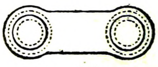

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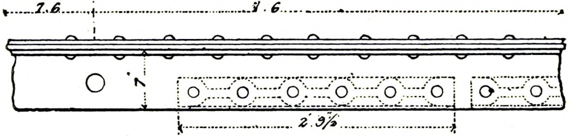
658.



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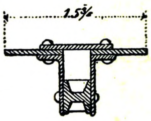
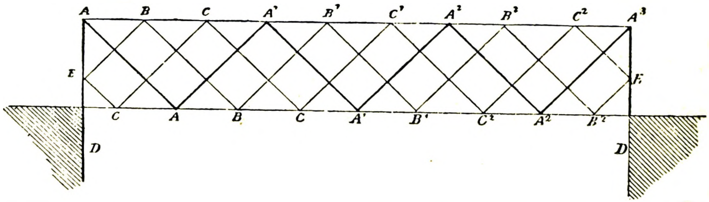


Lattice Girders.—The lattice girder, instead of consisting of a single system of triangles, embraces in the web several series of triangles, and from its greater lateral rigidity is better suited than the Warren for large spans. The introduction of the lattice girder marked an important epoch in bridge building, and the open web type has since maintained its ground with all engineers who understand the true economy of such structures. Different forms may be given to the flanges, but the peculiar character of the web constitutes the chief value.

660.



In Fig. 660 is represented the skeleton elevation of a lattice girder, with three series of triangles, A, B, and C, which practically are totally independent of one another. The load is supposed to be uniformly distributed over the top of the whole girder, and consequently equal portions of it are situated on the several apices of each system of triangulation.

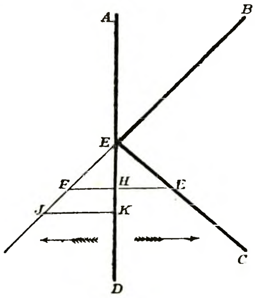
Let us take the case of the weight placed upon the apex A^1. It is, upon the principle of the lever, conveyed to each of the abutments D, by means of the bars A^1 A, A A, A D, A^1 A^1, A^1 A^2, A^2 A^2, A^2 A^3, A^3 D, and is considered to produce no practical effect upon the bars of the other systems, B and C, at the points of their intersections with its own system A.

It is assumed that whether pins or rivets be employed for connecting the diagonal bars of the different systems, they do not act as a medium for the transference of strain, but simply bind the bars together, or hold them in a vertical plane. Theoretically there is no doubt but that some slight strain is induced, but as we are dealing with the subject principally in a practical light, we shall not now discuss the question. There are two methods of arriving at the strains upon the web of a lattice girder, an approximate and an exact one. The former consists in supposing the total load distributed upon the apices of one system only, determining the strains, as in a Warren girder, and dividing them by the number of series or systems of triangles. Where the girder is small, and the systems of triangles do not exceed two, and the bars are pretty close together, this approximate method may suffice, but it should never be used upon a large scale, or where it is desirable to obtain a very accurate result. Referring to Fig. 660, and supposing the bars A A, A A^1 to be pairs, the strain upon either, divided into three parts, would not afford an accurate result for each of the corresponding bars of the other systems. To ascertain the strains not only upon the bars of the web of a lattice girder, but also upon the different parts of the flanges, there is but one true method, and that has been explained in the analysis of the Warren girder. In Fig. 660 the load should be considered as uniformly distributed, and the strains resulting from each separate weight obtained and tabulated as described. In applying the mathematical formula already given to the determination of the strain upon any bar of a lattice girder, care must be taken to include only so much of the load situated between the bar and the centre of the girder, as is placed upon the apices of that particular system of triangles to which the bar belongs.

So far, there appears to be no difference in the general disposition and nature of the strains induced upon both the Warren and the lattice girder. But if we examine the strains brought upon the vertical ends of the girders, or pillars, as they are usually termed, a notable difference will be perceived. Confining our attention to the one system of triangles in the elevation in Fig. 660, which commences at A over one abutment, and terminates at A^3 over the other, we may consider it to represent a Warren girder. Under these circumstances it has been already demonstrated that the only strain brought upon the end pillars A D, A^3 D, is a vertical one, which is equal, for each pillar, to half the total load upon the girder. This is worth remarking, as it points out that any vertical load will be ultimately transferred to the points of reaction, without altering its original value at those points, notwithstanding the manner in which it may be transferred, and the number of strains to which it may give rise in the various bars, considered to act as the medium of its transference. Again, referring to Fig. 660, and regarding it as the elevation of a lattice girder with three systems of triangles, it will be seen that two bars, B E, C E, are connected to the pillar A D, and two others, C^2 E, B^2 E, to the pillar A^3 D. Consequently, the strains upon these bars must be resisted by the pillar, and it remains to ascertain of what nature are the strains which the pillar undergoes. It will be sufficient to take the case of one pillar, A D. Of the two bars, one, B E, is a strut, and the other, C E, a tie; consequently their strains may be resolved into their components, one in a vertical, and the other in a horizontal direction.

This is shown in the diagram in Fig. 661, in which A D is the vertical pillar, and B E, C E the strut and tie. Let the compressive strain upon B E be equal to 1 ton; and since this tends to push the pillar A D outwards, produce the bar B E beyond the pillar, and lay off upon it the distance E F, representing 1 ton; draw F H to meet the pillar at H; then F H equals the horizontal component of the compressive strain upon the bar, and tends to push the pillar outwards. Now, suppose the bar C E to be under a tensile strain of 1 ton, it will evidently pull the pillar inwards, with the same amount of force with which B E pushes it outwards. Making E F represent 1 ton, and drawing F H to meet the pillar, it is plain that the horizontal components, being equal and in opposite directions, balance one another, and there is in that case no transverse strain upon the pillar. But if the strain upon one bar exceed that upon the other, then the transverse strain is equal in amount to the difference of their horizontal components. These horizontal components, which in the case of the intermediate bars B E, C E, must be resisted by the pillar A D, are analogous to those which are at the top and bottom of the pillar, and cause compressive and tensile strains respectively upon the upper and lower flanges.

661.



The object of departing from the simple Warren girder, and introducing secondary systems of triangles, is threefold. First, in the lattice type, the points of attachment between the upper and lower flanges are multiplied, and a more uniform distribution of stress is ensured; secondly, the flanges are not subject to any transverse strains from the cross girders or otherwise; and thirdly, the struts in the web itself are by mutual support made a great deal stiffer, and better adapted for the case of deep girders. It is evident that if the apices are too far apart, that is, if there are not a sufficient number of series of triangles, the assumption that a uniformly distributed load may be considered collected upon the apices, will not hold good, and the assumption becomes still farther from the truth, in the case of a moving or variable load. Each portion of the flange between the apices or points of attachment of the web, becomes in reality a short girder, and the entire flange approaches the conditions of a continuous girder. At the same time, since the real economy of the lattice form is to be found in its web, the bars must not be placed too near each other. In other words, there must not be too great a number of separate triangulations.

The simplest practical method of calculating the strains upon a girder, due to a passing load of uniform weight, is to calculate the strains upon the assumption that the total load upon the bridge, including its own weight, is uniformly distributed over the span. One advantage of this method is, that we at once obtain the maximum strains upon the different parts of the upper and lower flanges, since they take place when the passing load covers the whole span, that is, in reality, when it is uniformly distributed. The strains having been calculated upon this assumption, the design of the girder can be proceeded with; and the effect of the moving load upon the various bars, obtained by a graphical diagram, can be allowed for, by increasing their dimensions, if necessary, or by counterbracing. By counterbracing any portion of a structure, is meant, bracing it in such a manner as will enable it to resist a strain of compression as well as one of tension.

It is sometimes assumed that there is no strain upon the central bars of the web, simply because that is the condition obtaining under a uniform load; but Table III., which Fig. 662 illustrates, demonstrates the fallacy of all such loose conclusions.

662.

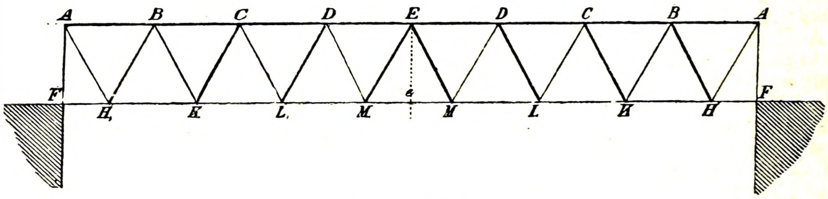


Table III.

Position of Load.	Bars.							
	AH	HB	BK	KC	CL	LD	DM	ME
H	− 5·41	− 0·36	+ 0·36	− 0·36	+ 0·36	− 0·36	+ 0·36	− 0·36
K	− 4·68	+ 4·68	− 4·68	− 1·07	+ 1·07	− 1·07	+ 1·07	− 1·07
L	− 3·96	+ 3·96	− 3·96	+ 3·96	− 3·96	− 1·80	+ 1·80	− 1·80
M	− 3·24	+ 3·24	− 3·24	+ 3·24	− 3·24	+ 3·24	− 3·24	− 2·52
M_1	− 2·52	+ 2·52	− 2·52	+ 2·52	− 2·52	+ 2·52	− 2·52	+ 2·52
L_1	− 1·80	+ 1·80	− 1·80	+ 1·80	− 1·80	+ 1·80	− 1·80	+ 1·80
K_1	− 1·07	+ 1·07	− 1·07	+ 1·07	− 1·07	+ 1·07	− 1·07	+ 1·07
H_1	− 0·36	+ 0·36	− 0·36	+ 0·36	− 0·36	+ 0·36	− 0·36	+ 0·36
Total	−23·04	+17·27	−17·27	+11·52	−11·52	+ 5·76	− 5·76	− 0·00

Position of Load.	Bars.							
	EM_1	M_1D	DL_1	L_1C	CK_1	K_1B	BH_1	H_1H
H	+ 0·36	− 0·36	+ 0·36	− 0·36	+ 0·36	− 0·36	+ 0·36	− 0·36
K	+ 1·07	− 1·07	+ 1·07	− 1·07	+ 1·07	− 1·07	+ 1·07	− 1·07
L	+ 1·80	− 1·80	+ 1·80	− 1·80	+ 1·80	− 1·80	+ 1·80	− 1·80
M	+ 2·52	− 2·52	+ 2·52	− 2·52	+ 2·52	− 2·52	+ 2·52	− 2·52
M_1	− 2·52	− 3·24	+ 3·24	− 3·24	+ 3·24	− 3·24	+ 3·24	− 3·24
L_1	− 1·80	+ 1·80	− 1·80	− 3·96	+ 3·96	− 3·96	+ 3·96	− 3·96
K_1	− 1·07	+ 1·07	− 1·07	+ 1·07	− 1·07	− 4·68	+ 4·68	− 4·68
H_1	− 0·36	+ 0·36	− 0·36	+ 0·36	− 0·36	+ 0·36	− 0·36	− 5·41
Total	− 0·00	− 5·76	+ 5·76	−11·52	+11·52	−17·27	+17·27	−23·04

The present example only includes the case when the load is situated upon the bottom flange; but, from what has been stated, there will not be the slightest difficulty in applying the same principle to the other instance, where the load is placed on the top. There is this difference to be remarked in the two examples;—When the load is at the top, the strains upon both diagonals nearest to the load will be compressive, and tensile when it is upon the lower member. To render the explanation complete, it is necessary to construct another table, showing the maximum strains of both kinds that the bars are subjected to. This is readily accomplished by adding together all the strains that have the same sign, and tabulating them under their respective bars. A reference to Table IV. will indicate at a glance the relative maximum strains that the bars in Fig. 662 are subjected to, by the action of a passing load of 0·5 ton a foot run.

If the load be supposed to advance from the opposite end of the girder, of course the bars will change places so far as the strains are concerned.

Table IV. shows that the maximum strain upon any bar takes place when the load covers the longer segment. The maximum compressive strain upon any bar that is a tie, takes place when the load covers the shorter segment, and the maximum tensile strain upon any strut under the same conditions. From this rule must be excepted the two central bars, which will be affected, accordingly as the load is on the upper or lower flange, in a different manner. The strains upon a lattice girder, with two or more systems of triangulation, resulting from a moving load, can be calculated by the rules already given, bearing in mind, that it is only the diagonals of that particular system upon the apices of which the load rests, that are affected by the load. The other bars suffer no strain until some of the apices belonging to their own system are loaded. In the present instance the moving load has been considered to be of greater amount than it really is, and the conclusion to be drawn from the investigation manifestly is, that in all bridges of small span, if the strains be calculated upon the assumption that the total load, live and dead, is uniformly distributed over the whole span, there is not much difference occasioned in the strains with the exception of the middle bars. But in practice these bars are generally of the same scantling as those in their immediate vicinity, and are therefore strong enough. The principle to be kept in view is, that if the permanent or dead load bear a very large proportion to the moving or live load, the effect of the latter in augmenting the maximum strains upon the bars will be very trifling. If, on the contrary, it be small, then the moving load will considerably modify the existing strains. It is a simple question of the preponderance of one load over the other. In practically designing the girder, care must be taken not to cut down the material too fine, especially when providing for the action of a moving load. This is the more necessary, as the strains that are calculated, are supposed to be simply those resulting from a load, successively superimposed upon different parts of the girder. No allowance is made in the theoretical calculation for the violent shock, concussion, and consequent vibration that attend the passage of a heavy train over a bridge. This must be allowed for by experience, by the introduction of such additional bracing as the skill of the engineer suggests. It is for this reason that the calculation of strains and the determination of the sectional area required, should proceed with the design and the actual drawing of the girder. It is not sufficient to design a structure that shall merely resist the forces to which it is subjected. It should resist them in the best and most economical manner, which can only be ensured by a practical knowledge of ironwork. It would be to little purpose to give the web of a plate girder the number of square inches required to resist the shearing strain, unless it were stiffened in a manner that would allow of its being able to receive the strain properly. Theoretically speaking, the web might be strong enough, but practically it might be so weak that it would buckle up under a fourth of the calculated strain.

TABLE IV.

Bars.	Maximum Compressive Strain in Tons.	Maximum Tensile Strain in Tons.	Bars.	Maximum Compressive Strain in Tons.	Maximum Tensile Strain in Tons.
A H	0·00	23·04	E M_1	5·75	5·75
H B	17·63	0·36	M_1 D	3·23	8·99
B K	0·36	17·63	D L_1	8·99	3·23
K C	12·95	1·43	L_1 C	1·43	12·95
C L	1·43	12·95	C K_1	12·95	1·43
L D	8·99	3·23	K_1 B	0·36	17·63
D M	3·23	8·99	B H_1	17·63	0·36
M E	5·75	5·75	A H_1	0·00	23·04

In railway bridges the bending moment is always somewhat greater than that due to the dead weight of the train, because irregularity of road, wind pressure, and other disturbing causes tend to increase the stresses. Again, it is now universally admitted that a lower working strain should be taken in structures subject to frequent bendings, and in which the live load is considerable as compared with the dead. The following table, due to B. Baker, exhibits the rolling load and working tensile strain which it would be advisable to adopt for first-class railway bridges in England ;—

TABLE V.—ROLLING LOADS AND STRAINS ON RAILWAY BRIDGES, BAKER.

Span.	Rolling Load a Foot Run, Single Line.			Tensile Strain a Square Inch.		
	Normal.	Increase.	Effect.	Standard.	Decrease.	Working.
	cwt.	per cent.	cwt.	tons	per cent.	tons
10	60	20	72	5	20	4
20	48	10	53	„	18	4·1
30	42	7	45	„	16	4·2
60	30	3	31	„	13	4·3
100	27·5	Nil	27·5	„	10	4·5
150	25	„	25	„	5	4·75
200	22·5	„	22·5	„	Nil	5
275	20	„	20	„	Nil	5

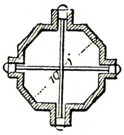
Where long struts are used, the unit strain should vary according to the length. American engineers have given great attention to this question, and have made many experiments. The following are the results obtained, in one very important series of experiments on the strength of wrought-iron columns of varying sections, and formed part of the specification for the bridges on the Cincinnati Southern railways ;—

Table VI. contains the average or mean results of experiments made on wrought-iron columns and struts of various kinds, prepared by four bridge companies.

TABLE VI.—EXPERIMENTS ON WROUGHT-IRON COLUMNS.

Length of Column.		Sectional Area in Square Inches.	Pressure a Square Inch causing Fracture in lb. $= \frac{P}{S}$.	Figs. referred to.
feet	in.			
5	0	14·25	33,600	663
15	0	14·09	37,500	664
15	0	14·62	30,000	665
15	0	23·67	32,000	666
26	0	25·05	24,000	667
26	0	13·60	30,000	668
28	$6\frac{3}{8}$	5·68	31,700	669
12	3	6·00	17,600	670

663.



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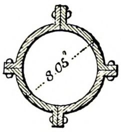

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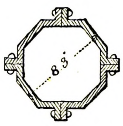

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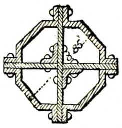

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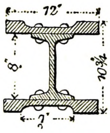

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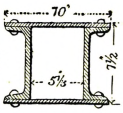

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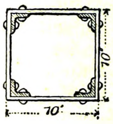

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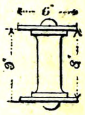


From this table the value of the constant f can be calculated for each column, by Gordon's formula, and also by the formula given by Rankine, in which the radius of gyration of the section is used in place of the smallest diameter, for by substituting m for the fraction $\frac{a\,l^2}{1 + h^2}$ or for $\frac{a'\,l^2}{1 + r^2}$, there results $f = \frac{m\,P}{S}$, the dimensions to satisfy which are all given in the table.

Gordon's formula .. .. $\frac{P}{S} = \frac{f}{\frac{a\,l^2}{1 + h^2}}$

Rankine's formula .. .. $\frac{P}{S} = \frac{f}{\frac{a'\,l^2}{1 + r^2}}$

P being the ultimate load producing the crushing or bending of column.
S, sectional area of column in square inches.
f constant, supposed to be equal to the ultimate resistance a sq. in. of a short column, whose length is equal to its diameter.

a constant {For columns with flat bearings .. .. $= \frac{1}{3000}$
For columns with flat bearing at one end and rounded at the other $= \frac{2}{3000}$

a' constant {For columns with flat bearings .. .. $= \frac{1}{36000}$
For columns with flat bearing at one end and rounded at the other $= \frac{2}{36000}$

l, length of column in inches.
h, diameter of column in the direction of its great deflection.
r, radius of gyration of cross section of column in the direction of its greatest deflection.

In order to test thoroughly the mathematical correctness of the formula, experiments should have been made with the same pressure on columns of different lengths and shapes of cross section, made of the same iron, of uniform quality, and all fittings made and measurements taken with great precision. All these conditions could not be realised. But for the objects in view, which were to ascertain whether the formula could be applied in practice, with very approximately correct results, and if so, to determine the correct value of the constant f, scientific nicety was not necessary; it was preferable, on the contrary, that the conditions of the experiments should be the same as those actually met with in posts and struts, as they stand in iron structures.

The following general conclusions can be drawn from the examination and comparison of all the tests made on columns;—

For columns of the same shape, of different lengths, made of the same kind of iron, the values of f calculated from the formulæ, do not differ more than can reasonably be accounted for by the ordinary want of uniformity in the quality of the iron, the differences not being greater than those between the ultimate tensile strengths, obtained with specimens of iron of the same manufacture.

For columns of different shapes of cross section, and made of different kinds of iron, the values of f calculated do not vary more than does the strength of iron of different manufacturers. Columns, however, should be tested in a vertical, and not in a horizontal position as these were. But if tested horizontally, each column should be counterweighted with a weight equal to half its own weight, attached by a chain to the centre, and passing over a pulley.

Gordon's and Rankine's formulæ must both be considered as practically correct, for columns with flat bearings at the ends, of different lengths and shapes of cross section, provided the ultimate strength of one column made of the iron to be used be determined, so that the value of the constant f to be applied in the formulæ may be calculated. This constant being very approximately proportional, but not equal to the ultimate strength of the iron, and not the same in the two formulæ, being smaller for Rankine's than for Gordon's.

For columns hinged on pins at the ends, Gordon's and Rankine's formulæ for columns rounded at one end and fixed at the other, will give approximately correct results, provided f be determined as noted above.

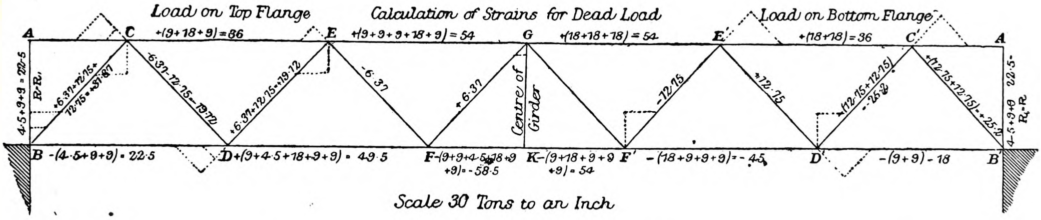
For swelled columns, the formulæ are also applicable, provided the diameter at the end be used.

It is of great importance for all built columns, and especially for open columns, that the several parts should be well riveted at the ends, and that true and even bearings at the ends be obtained.

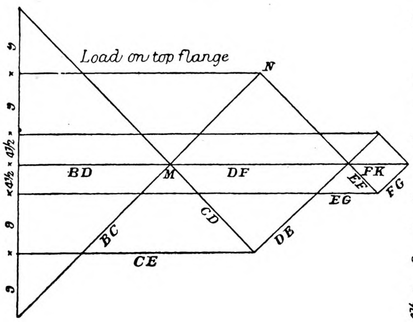
Some of the tests confirmed the fact already pointed out by some experimenters, but not universally admitted, that wrought iron, when submitted to a pressure beyond that corresponding to its limit of elasticity, and allowed to rest, will afterwards possess a higher limit of elasticity.

Diagram of Forces.—The strains upon an open-web girder may be obtained from a diagram of forces, Figs. 671 to 674, in which each line gives the total strain upon any particular member of the girder; the strains are first deduced by the successive resolution of the weights at each joint and subsequent summation, as shown in Fig. 671. A comparison of the strains by scale will point out that the totals agree with complete accuracy. Fig. 671 represents an open-web girder, with the strains calculated upon the one half, on the supposition that the weights are situated on the top flange, and on the other half that they are placed upon the bottom flange. The girder is 60 ft. in clear span, with a depth of one-sixth of the span.

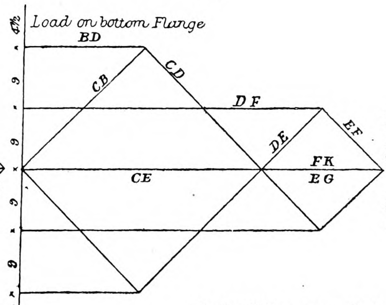
671.


Load on Top Flange
Calculation of Strains for Dead Load
Load on Bottom Flange
A
C
+(9+18+9)=36
E
+(9+9+9+18+9)=54
G
+(18+18+18)=54
E'
+(18+18)=36
C'
A
4·5+9+9=22·5
R-R,
+6·37+12·75+12·75=+31·87
-6·37-12·75=-19·12
+6·37+12·75=+19·12
-6·37
+6·37
Centre of Girder
-12·75
+12·75
+(12·75+12·75)=25·2
+(12·75+12·75)=+25·2
22·5
4·5+9+9
R₁-R
B -(4·5+9+9)=22·5
D+(9+4·5+18+9+9)=49·5
F-(9+9+4·5+18+9+9)=-58·5
K-(9+18+9+9+9)=54
F' -(18+9+9+9)=-45
D'
-(9+9)-18
B'
Scale 30 Tons to an Inch

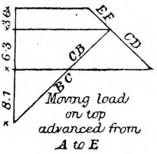
672.


Load on top flange
N
BD
M
DF
FK
EF
FG
EG
CD
BC
DE
CE
9
9
4½
4½
9
9

673.


Load on bottom Flange
BD
CB
CD
DF
DE
EF
FK
CE
EG
4½
9
9
9
9
4½

674.

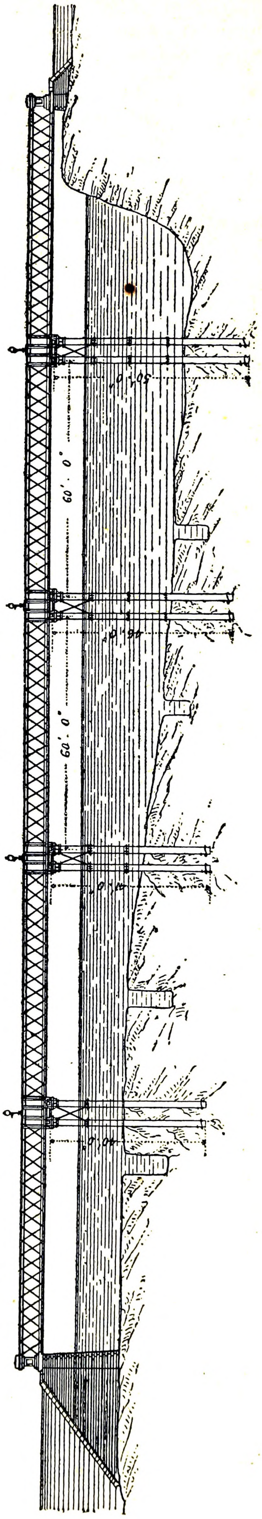

EF
CD
CB
BC
3·6
6·3
8·1
Moving load on top advanced from A to E

Scale 30 Tons to an Inch

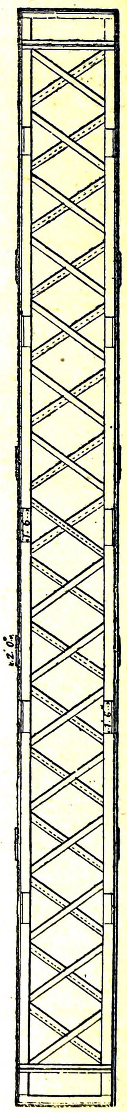
The total half-load $= R = R_1 = 22 \cdot 5$ tons, which gives 9 tons at each apex. The dotted lines in Fig. 671 represent the strains, and the diagram of forces for the strains with the load on the top flange is given in Fig. 672, and for those on the bottom in Fig. 673. Supposing the moving load to have advanced from A to E, the strains will be found given in the diagram of forces in Fig. 671. It will be observed that there is some difference in the amounts of the strains induced on the different members of the girder, accordingly as the load is situated on the top or bottom flange. When the load is situated on the upper flange, the total strain upon the centre of the lower flange is greater than when the load is on the lower flange itself. The strains, in fact, upon all parts of the lower flange are greater when the load is placed at the top, while under both cases of loading, the strains upon the different parts of the upper flange remain the same. So far therefore as the weight of metal in the flanges is concerned, it would be more economical to load a girder upon the lower than upon the upper flange, and in practice this is generally found. Inspection of Fig. 671 will show that with the load on the upper flange, the strains upon the diagonal bars in the web are also greater than when it is placed on the lower flange. The strain upon the centre diagonals is 6·37 tons instead of zero, and upon the end bars 31·87 instead of 25·20 tons. The value of the reaction at the abutment will be the same in either case, that is, $R = R_1$. The diagrams of forces in Figs. 672 to 674 are reciprocal diagrams. In other words, all the bars enclosing a space in Fig. 671 will meet in a point in the diagrams. In comparing these two methods of calculating the strains, this peculiarity will be found very useful, as it will enable the lines representing the different parts of the girder to be readily ascertained. For example, take the triangle B C D in Fig. 671 formed by the bars B C, C D, and B D. The strains upon these are represented in the reciprocal diagram Fig. 672 by the corresponding lines B C, C D, and B D, which all meet in the point M. The lines in the diagrams are lettered only for the strains upon half the girder, although the diagrams are drawn for the whole girder, the unlettered lines, which are exactly equal in length to the lettered lines, representing the strains upon the other half.

Lattice Girders.—The practical example, of which the particulars are given in Figs. 675 to 685, is a design for a large public road bridge in India, and is shown in general elevation in Fig. 675. The bridge consists of five spans of 60 ft. each between the centres of the nearest columns. The columns and screw piles which carry the bridge are of cast iron, and are in pairs, with a distance of 4 ft. 6 in. between centres. The girders are not continuous over the piers formed by the double columns, and are of wrought iron, having a depth of 5 ft. 6 in. from out to out of flanges. The web has two series of triangles, or one intersection of the diagonal bars at exactly the half depth between the flanges. Each girder bears at the extremity upon the column nearest to it, and throws no weight upon the other, which is supposed to carry its own load, in supporting the adjoining girder. A cast-iron bed-plate, under the bearings of the girder, connects the heads of the twin column, so that in the event of any slight settlement taking place in one of the columns and not in the other, the unyielding one would be able to assist that adjacent to it, supposing the cast-iron bed-plate did not give way, under the cross strain caused by the difference in level of the ends of the two girders.

Fig. 676 is an elevation of one girder. The upper flange is composed of two angle irons 6 in. × 3½ in. × ½ in., and one horizontal plate, continuous throughout the girder, 18 in. × 7 in. at the centre for a distance of 10 ft. 6 in., 18 in. × ¾ in. for a distance of 10 ft. 10 in., and 18 in. × ½ in. for the remainder of the flange. The lower flange is similarly built up, with the exception that the horizontal plates are of different lengths, and vary in thickness from ½ in. to ¾ in. The rivets are ⅞ in. in diameter, and have a pitch of 4½ in. from centres. The diagonal bars in the web are inclined at an angle of about 60°. The struts are of T iron, and are double, varying in dimensions from 3 in. × 2 ft. 2 in. × $\frac{5}{16}$ in. to 5 in. × 3 in. × ⅜ in. The ties are of bar section, and are also in pairs. Their scantlings vary from 4 in. × ⅜ in. to 5 in. × ½ in. At the centre the diagonal ties are of T iron, the web being thus counterbraced at that point. The covers are all 2 ft. long × ⅞ in. thick. Figs. 677, 678, are an end elevation of one of the main girders over the pier, together with a section of some of the cross-girders. A sectional plan in Fig. 679 is taken through Fig. 677, and shows the arrangement of the cross girders, the longitudinal T iron or runners, and the diagonal horizontal bracing. The cross girders are spaced every 3 ft. 7½ in. from centre to centre, except near the piers, where the distance is increased to 4 ft. 7½ in. Over the piers the distance is reduced to 4 ft. 6 in., which is equal to the distance between the centres of the twin columns. A solid wrought-iron plate 18 in. × ½ in. in thickness is riveted to the back of the ends of the girders, which are thus closed in at the extremities. Fig. 680 is a transverse section of this bridge. The breadth of the flange is 18 in., the depth of the main girders 5 ft. 3 in., and the inside width of bridge in the clear 18 ft. The cross girders are of the trussed form, and are constructed of flanges of T iron 5 in. × 4 in. × ½ in., and lattice bars. The struts and ties in the main girders are braced together in the cross section by diagonal bars 2½ × ¼ in., 2 in. × ¼ in. For so short a strut, with the exception of a horizontal piece at the centre of the section, this bracing is superfluous. Between the cross girders, T irons, at intervals of 3 ft., are fixed, to which the buckled roadway plates are riveted. Upon them is placed the asphalte, and a gutter 15 in. wide is provided at each side of the roadway. It is to be observed that the T iron of the lower



675.

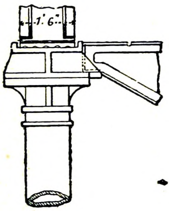


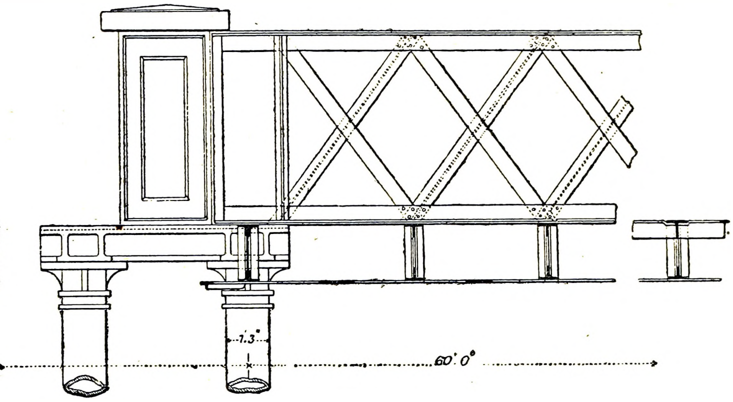
676.

flange of the cross girders is forged all round the ends, and an end plate $\frac{3}{8}$ in. thick forms the termination of the girders. The cross girders are all riveted to the bottom flange of the main girders, and are suspended from them by the rivets, a mode of fastening which is not so good as if they rested directly upon the lower flanges in the openings, or diamonds between the lattice bars.

677.

678.





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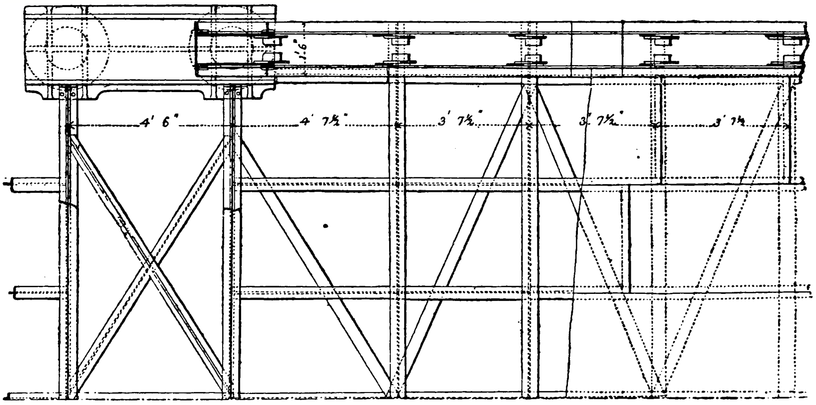

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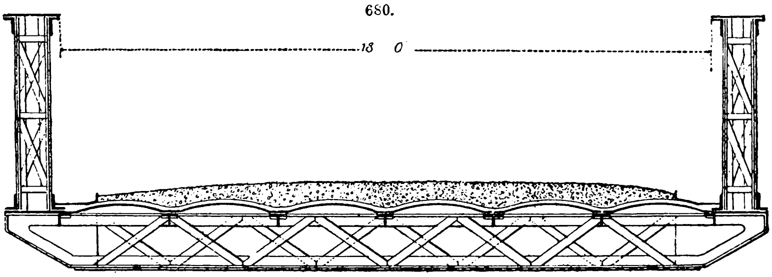

In Figs. 681 and 682 are the columns and cross bracing. The horizontal bracing consists of a transverse plate girder at the top of the columns, underneath the bearings of the main girders, and a pair of T irons 4 in. × 3 in. × $\frac{3}{8}$ in. lower down, where the flange joints of the columns occur. Between these vertical points diagonal bracing, composed of double T irons 5 in. × 3 in. × $\frac{3}{8}$ in., is fixed to the columns by wrought-iron rings or collars, and wrought-iron bolts $1\frac{1}{4}$ in. in diameter. A similar description of bracing is fixed in the same manner to the double columns in the plane of the main girders as in Fig. 681. The rings or collars, which are all $\frac{1}{2}$ in. in thickness, are shown in Figs. 683, 684. Double fillets are cast upon the columns, between which the rings are placed and bolted to the bracing. Lugs are frequently cast on the columns for attaching the cross bracing instead of rings. It is objected that the rings are very often broken, but if they are made sufficiently strong, this objection has no real force. They are much cheaper than the collars. Fig. 685 represents an elevation of a portion of one of the screw piles. The pitch of the screw is 8 in., and it makes one complete turn and a half round the body of the pile, which has uniform thickness of metal $1\frac{1}{8}$ in.

Bowstring Girders, Strains.—The calculation of the strains upon the various parts of girders which have one or both of their flanges curved, is much more complicated than that belonging to the class of structures we have been considering, in which both flanges are horizontal. This is chiefly owing to the continuous variation of the angle of inclination of the curved flange, as well as of the diagonal bars in the web. In addition, by reason of its form, the girder trenches upon principles which do not prevail in the horizontal type of construction. It was found that the rule in straight girders indicated a varying strain throughout the flanges, diminishing from a maximum at the centre to zero at the ends. The reverse took place in the web, except under special conditions of loading. With a uniformly distributed load, the diagonal bars underwent a minimum strain at the centre, equal to zero, and a maximum at the ends, the amount of the latter being invariably equal to half the total load upon the girder, multiplied by the cosecant of the angle of the inclination of the bar to the horizon. These conditions do not prevail in the class of girders we are about to investigate, but are almost completely reversed. In the flanges the strains become nearly uniformly equal, throughout the whole length of the girder, and the maximum strains of compression and tension occur in the diagonal bars, situated not near the ends, but at the centre of the span. In Fig. 686 is represented a bowstring girder, with a single system of triangular bracing. The span is 40 ft., the depth at the centre 5 ft., and the rate of loading 1 ton a foot run upon the bottom flange. It is required to find the strains upon the flanges and web, under all conditions of loading. In this case it is better to ascertain the strains for each weight in succession, as the addition and subtraction of those of different sign, will determine the strains for a uniform load. When it is only necessary to ascertain the strains for a uniform loading, there is a readier and simpler means of determination, but in the case of a large girder it would be necessary to follow the course we are about to adopt. The load at each apex, referring to the diagram, will consequently be equal to 5 tons, and, upon the principle of the lever, this will be transferred to each abutment, in portions in the inverse ratio of their corresponding distances. Let us commence with the 5 tons at the apex F′. Of this weight, $\frac{5 \times 7}{8} = 4 \cdot 375$ tons will be transferred to the abutment A′, and the rest, or 0·625 ton, conveyed to A. It is with this

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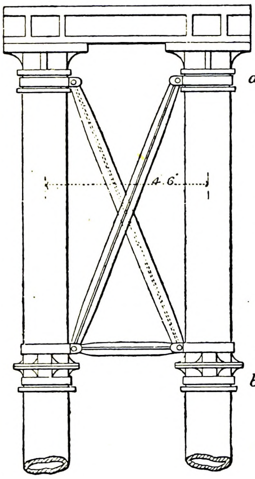

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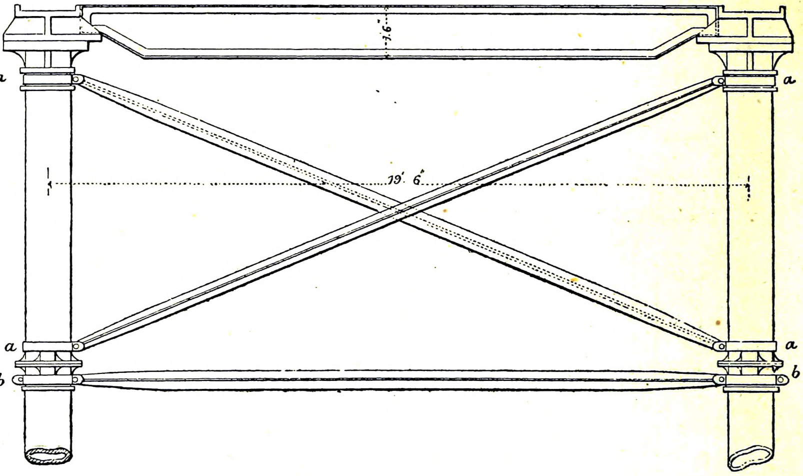

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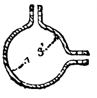

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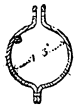

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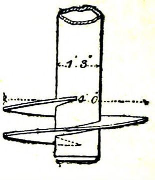

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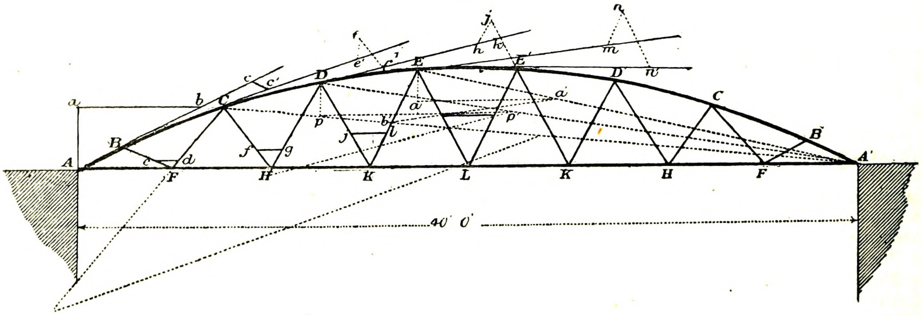

latter weight we are at present concerned, as it represents the vertical reaction at A. It is finally conveyed to the abutment by the portion of the upper flange represented by A B, and on arriving at A, is resisted by the whole of the lower flange in general, and by the last bar of it, A F, in particular. The first step is to produce all the separate bars A B, B C, C D, D E, E E′ of the upper flange to any convenient length, as shown in Fig. 686. Although, practically, the curve of the upper flange is an arc of a circle, yet for all the purposes of calculating the strains it is regarded as a polygon, the sides of which are obtained by joining, by straight lines or chords, the respective apices of the triangles. The scale upon which Fig. 686 is drawn is almost too small to indicate the difference, but the left-hand half of the upper flange is shown as a polygon, while the right half is an arc of a circle. Where an approximate method, by the usual formula for horizontal girders, is employed for determining the strains upon the bow and the string, the upper curve is considered to be a parabola. The weight of 0·625 ton being the vertical reaction at A, make A a equal to it upon any convenient scale, and draw ab to meet A B produced, ab and A b will equal the strains upon A F and A B, due to the portion of the weight at F′, which is conveyed to A. The strains upon B C, B E, and F H are now required. Upon A B produced lay off B c = A b, draw cc' parallel to B F to meet B C produced; B c' is the strain upon B C, and cc' that upon the bar B F, the former being compressive and the latter tensile. If cc' be now laid off upon the bar B F, and cd drawn parallel to the lower flange, then cd will equal the strain upon F H, and F d that upon the bar F C. The total strain upon F H will equal $ab + cd$. The strains upon C D and C H may be obtained from those already found for B C and F C, and there are two methods of determination. They may be deduced by taking the strains upon B C and F C separately, and resolving these in the directions of C D and C H, or by first finding the resultant of the former strains, and then completing the parallelogram of forces. To find the strains upon C D and C H, plot off upon B C produced, the length C e' = B c', and from e' draw $e'f'$ parallel to F c and equal F d. A line drawn from C to f' would represent the resultant of the strains in B C and F C. From the point f' draw fg' parallel to C H, and C g' represents the strain upon C D, and $f'g'$ that of tension upon C H. Making H f = $f'g'$ draw fg parallel to the lower flange, and fg gives the strain upon H K, and H g that upon the bar H D. The total strain upon H K equals, consequently, $ab + cd + fg$. The determination of the strains upon the remaining bars, due to the reaction of a weight of 0·625 ton at A, is merely a repetition of the method already described, and is shown in the figure by the dotted lines. The action of the weight at F′ is now accounted for, and we may proceed to consider that of the next 5 tons placed at H′. The portion of this weight that is transferred to the abutment A is equal to 1·25 tons, or exactly double that resulting from the action of the weight at F′. The effect of its reaction at A will therefore be just double that of the former weight, and it only remains to double the strains already arrived at. Similarly, for the weights situated at the apices K′ and L, all that is necessary is to multiply the strains already found for the weight at F′ by three and four, and we have those for these two other weights. No sooner do we come to the weights situated at the apices upon the other side of the centre of the girder, than this rule no longer holds for all the parts of the flanges and web. To consider the flanges first, and the weight at K. This weight, since its reaction at the abutment is five times that of the weight at F′, will affect the upper flange from A to E, and the lower from A to K to five times the extent of that weight, and the strains can be inserted in the table upon those parts of the flanges situated within these limits. The strains upon E E′ may, however, be readily arrived at by inspection, as it is evident that the weight at K affects these parts of the girder to precisely the same extent as those at K′, the corresponding apex upon the opposite half of the girder. The strains upon the central portion E E′ of the upper flange may be at once written down, since the remaining strains from the weights H and F equal those already found for H′ and F′. All the strains upon the central part E E′ of the upper flange having been calculated, it remains to determine those upon the remaining parts of both upper and lower flanges, and upon the diagonals in the web. The effect of the weight at H has now to be considered. The strains upon A B, B C, and C D are obtained, as already explained, by simply multiplying by six the strains upon those members due to the reaction of the weight at F′, and therefore there remains to be determined the strain upon D E, due to the weight at H. This strain is twice that due to the weight at F. Draw E A′; from E lay off E a = 0·625 ton = the reaction at A′ of the weight at F. Draw aa' horizontal, and $a'b'$ parallel to D E; then $a'b'$ is the strain upon D E from the weight at F, and twice this equals the strain required. It only remains now to account for the strains upon A B, B C, C D, from the weight at F, to complete all the strains upon the upper flange. The strains upon A B, B C are respectively equal to seven times those found for the weight at F′; to obtain the strain at C D, we proceed as for D E. Draw D A; plot D p as before 0·625 ton; make pp' horizontal, and draw p'H parallel to C D, then p'H equals strain upon C D, thus completing the strains upon the upper flange. The strains upon the lower flange are those upon K L, due to the weights at K, H, and F; those upon H K and F H, due to the weights at F and H; and that upon F H due to the weight at F. If we find the strain upon K L due to the weight at F, the strains due to the weights at H and K will be respectively twice and three times the amount. This strain upon K L, due to the load at F, is equal to the line aa' in the diagram, and therefore the other strains are known. Similarly, the line pp' is equal to the strain upon H K from the load at F, and twice this is the strain upon the same part from the weight at H. Lastly, the strain upon F H, due to the weight at F, may be determined by drawing the resultant C A′ and proceeding as before. This last resolution of forces is not given in the diagram, but it is precisely similar to that performed at the apices D and E. The remaining strains upon the bars present no difficulty. To determine the strains upon the other bars it is only necessary to find that due to the weight at F, of which the others are multiples.

To ascertain the strains upon the various bars under the condition of a uniform load, it is only necessary to subtract the separate plus and minus strains, and the total will give the desired information.

Instead of ascertaining the strains by prolonging the parts of the upper flange, another method may be employed, by drawing lines from each apex to one of the abutments, plotting upon a vertical line the amount of any weight which is transferred to the abutment by that line, and resolving in the directions of the parts of the girder affected. When this method is adopted, it is only necessary to follow the action of the weight at the apex F or F′, throughout the whole of the girder, as from this action all the other strains can be determined. By this method the strains upon the parts of the upper flange are well checked, as the strain upon each separate part is twice determined. Suppose that we are following the action of that portion of the weight at F, which is transferred to the abutment A′, and have arrived at any particular apex A. Let A M, Fig. 687, represent the direction of the resultant at A, or the line joining the apex A with the point A′ in Fig. 686. Make A *a* = that portion of the weight conveyed to the abutment at A′. Draw *a b* horizontal and *b e* parallel to A C, then *a b* equals the strain upon E B, *b e* that upon the top flange A C, and A *e* that upon the bar A B. The next point is to determine the strain due to the same weight upon the upper flange C F, the lower B D, and the bars C B and C D. Make C *a* = A *a*, and proceed as before, first drawing C N to represent the line of transmitted pressure. Then *a d* equals the strain upon B D, *d g* that upon C F, C *d′* that upon C B, and C *b* that upon C D. But to obtain the strain *c d′* upon the bar C B, draw the line *d d′* parallel to A C. This line also represents the strain upon A C, and consequently *d d′* = *b e*. Thus, knowing the vertical component of the strain at any apex, we can determine the strain upon the two bars meeting at that point, and that upon the two separate parts of the upper flanges, meeting the bars at the same apex. Another advantage of this method is that it gives the strain upon the different parts of the lower flange at once, without the necessity of adding increments.

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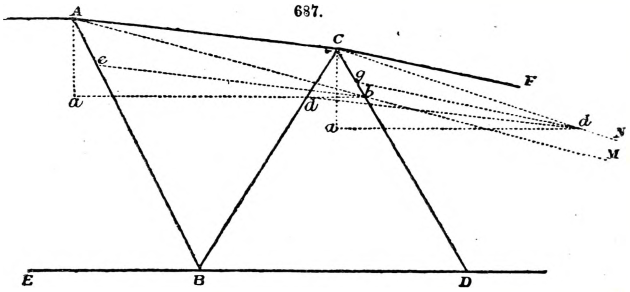

TABLE VII.—STRAINS ON FLANGE OF BOWSTRING GIRDER.

Weight at	Parts of the Flange.								
	A B.	B C.	C D.	D E.	E E′.	A F.	F H.	H K.	K L.
F′	+ 1·38	+ 1·51	+ 1·70	+ 1·95	+ 2·45	− 1·22	− 1·48	− 1·83	− 2·35
H′	+ 2·76	+ 3·02	+ 3·40	+ 3·90	+ 4·90	− 2·44	− 2·96	− 3·66	− 4·70
K′	+ 4·14	+ 4·53	+ 5·10	+ 5·85	+ 7·35	− 3·66	− 4·44	− 5·49	− 7·05
L	+ 5·52	+ 6·04	+ 6·80	+ 7·80	+ 9·80	− 4·88	− 5·92	− 7·32	− 9·40
K	+ 6·90	+ 7·55	+ 8·50	+ 9·75	+ 7·35	− 6·10	− 7·40	− 9·15	− 8·45
H	+ 8·28	+ 9·06	+10·20	+ 6·80	+ 4·90	− 7·32	− 8·88	− 7·80	− 5·60
F	+ 9·66	+10·57	+ 5·10	+ 3·40	+ 2·45	− 8·54	− 6·45	− 3·90	− 2·80
Total ..	+38·64	+42·28	+40·80	+39·45	+39·20	−34·16	−37·53	−39·15	−40·35

TABLE VIII.—STRAINS ON BARS OF THE WEB OF BOWSTRING GIRDER.

Weight at	Bars of the Web.						
	B F.	F C.	C H.	H D.	D K.	K E.	E L.
F′	−0·20	+0·11	−0·29	+0·27	−0·42	+0·40	−0·74
H′	−0·40	+0·22	−0·58	+0·54	−0·84	+0·80	−1·48
K′	−0·60	+0·33	−0·87	+0·81	−1·26	+1·12	−2·22
L	−0·80	+0·44	−1·16	+1·08	−1·68	+1·60	−2·84
K	−1·00	+0·55	−1·45	+1·35	−2·10	−3·30	+2·22
H	−1·20	+0·66	−1·74	−4·2	+2·4	−2·20	+1·40
F	−1·40	−5·70	+2·4	−2·1	+1·2	−1·10	+0·74
Total ..	−5·60	−3·39	−3·69	−2·25	−2·70	−2·68	−2·84

The maximum tension and compression upon any bar may be obtained at once by the diagram. Thus, to find the maximum compression upon the bar E L, Fig. 686, make E *a* equal the sum of those portions of the weights situated at the apices between E L and the abutment A′, that are transferred to A′, and proceed as described. The maximum compression can also be obtained by estimation, for the sum of the weights acting upon the bar E L will equal 1 + 2 + 3, multiplied by the transferred portions of the weight at F.

Referring to Table VIII. of strains on bars of the web, the compressive strain upon E L due to the weight at F is 0·74. The maximum compressive strain is therefore 1 + 2 + 3 = 6 + 0·74 = 4·44 tons, which should tally with the result of computing the strain by algebraic addition of all the separate strains upon the same bar.

This investigation demonstrates that the result of curving the top flange of a girder, is to relieve the web of a portion of the shearing strain, which, in a horizontal girder, it alone resists. Consequently, if the curvature be increased until it assumes a parabolic form, the top flange takes the whole shearing strain if uniformly distributed, and there is none whatever on the web.

Bowstring Girder. Practical Example.—The example, Fig. 688, is a bowstring girder erected over the Grand Surrey Canal, on the East London Railway, by Hawkshaw. The span in the clear of the main girders is 80 ft., and the depth of the girder in the centre one-tenth of the span. It will be noticed that there are two systems of triangulation in the web of these girders. The analysis of the strains upon this description of girder was made on the assumption that there was only one series of triangles. The same method may be adopted in this case, and the strains may be calculated for each series of triangles, or one system only may be subjected to analysis, and the results divided by two for the actual strain upon any particular bar. In the latter case, care should be taken to select that system which will make the strains a maximum. There are three main girders in the width of the bridge, the centre one being made proportionally stronger than the other two, as it has a greater share of the load to carry. With the exception of a difference in the scantlings, the form of the three girders is the same. An elevation of half the central main girder is shown in Fig. 689. The upper and lower flanges are composed of plates, angle irons, and deep vertical plates, in the usual trough form. The vertical plates are 1 ft. 3 in. deep, and thus afford abundant rivet space for the diagonal bars in the web. These are spaced at unequal distances, varying from 3 ft. 6 in. at the ends of the girder to 6 ft. at the centre. By this arrangement the angle which the bars make with the horizontal is maintained constant, whereas, had the spaces or diamonds been made all equal, the angle of each bar must have been different. In large girders the angle cannot be kept constant throughout the whole web, whether the spaces be equal or not. It will be observed that the scantlings of the diagonal bars increase towards the ends of the girder, more than might be supposed from the example we have analyzed. This arises from the fact that the upper and lower flanges in Fig. 689 are not continued until they meet, and therefore the full principle of the bowstring girder does not come into play. The dimensions of the bars, which are all double, vary from $4\frac{1}{2}$ in. × $\frac{5}{8}$ in. at the centre to 7 in. × 1 in. at the ends. Both struts and ties are plain bars. The former are so short between their supported points as not to be liable to bending action; otherwise, the plain bar section is not the proper one for the struts of an open-web girder. An end plate is riveted on at the junction of the upper and lower flanges. A plan of a portion of the upper flange, Fig. 689, shows the manner in which the riveting is arranged in the breadth of the flange. A cross section of one-half of the bridge, Fig 690, indicates at once, by the manner in which the iron girders are built up, how limited was the headway. The cross girders are of very peculiar shape, and the flanges of the rails are brought level with the top of the girders by means of 12-in. balks framed in between the cross girders, upon which they rest. The main girders have double webs, but no cross bracing. Diaphragms of wrought-iron plates and angle irons are fixed between the bars of the webs, both at top and bottom, Fig. 690, at those points where the cross girders are placed, to which they are riveted. The cross girders are spaced at intervals of 4 ft. from centre to centre. They are constructed of angle irons and plates, and with the exception of their being deeper at the ends than at the centre, are of the ordinary small plate-girder description. The longitudinal timbers or runners which carry the rails are 12 in. × 9 in., and are fixed to the cross girders by angle-iron knees. Cast-iron plates cover in the space between rails.

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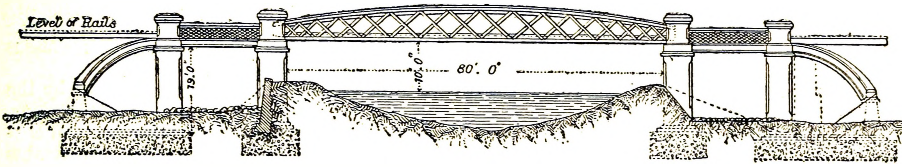

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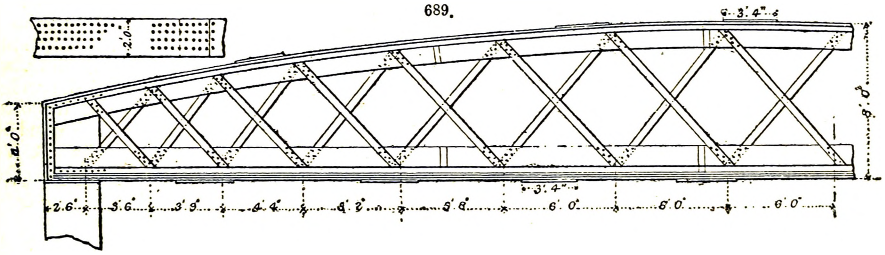

The Braced Arch.—If for the solid web of the plate arch, of which practical examples have been given, be substituted an open web, we have the braced arch, or more properly the braced rib, the distinction between the two being precisely analogous to that between the two descriptions of ordinary girders. In the braced arch we do not include what is frequently so termed, namely, a braced girder having the lower flange curved and the upper horizontal, but an arch consisting of curved upper and lower flanges, connected together by a cross bracing. There are three general classes of braced arches;—Arches continuous through the crown, and hinged only at the springings. Arches hinged both at the crown and at the springings. Arches which are continuous at the crown and fixed at the springings. The last of these represents most nearly the corresponding solid or plate arch, and is the description to which we shall confine ourselves. It is the best adapted for actual construction, although examples of the other classes are not wanting. There are, however, very few examples of the braced arch of any class.

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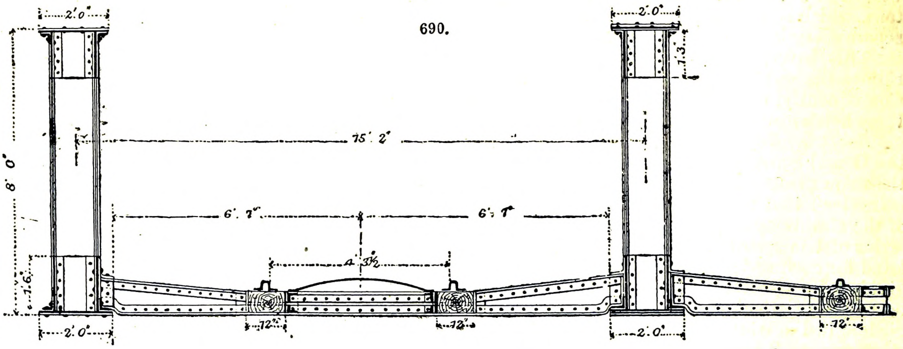
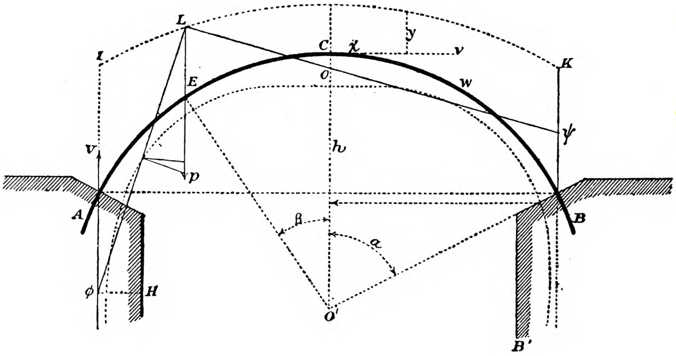


Strains upon the Braced Arch.—The strains upon the braced arch may be calculated, either by the graphical method described for other forms of girders, or by the method of moments or sections. The most useful example in practice is the case in which the arch is fixed at both ends, and continuous over the crown. The following is the method by which Dubois calculates the strains upon an arch of this description. This is by far the most important case of braced arch, as by the continuity of the crown and fixity of ends we obtain all advantages due to combined strength and elasticity. It is also the most difficult case for solution, as the formulæ obtained by a mathematical investigation are complex, and give rise to tedious and laborious computations. A method combining simple analytical results with graphical construction, similar to the preceding, will obviate these difficulties. In the present case, as before, the common intersection of the weight and the reactions lies in a curve, the equation of which may be found, and the curve itself plotted, for any given case. But this curve, or locus I L K, Fig. 691, being constructed, in order to find the directions of the reactions, which now no longer pass through the ends of the arc A and B, it is necessary to find and also construct the curve developed by these reactions for every position of P

691.



that is, the curve to which these reactions are tangent. If, then, these two curves are constructed, we have only to draw through L, Fig. 691, lines tangent to this enveloped curve, and we have at once the reactions in proper direction, and by resolving P along these lines can easily find their intensities, and therefore V and H, as before. Second circular arc: In this case we have for locus I L K, Fig. 691, and for the small central angles α, the equation

$$y = \tfrac{1}{5} h \left[1 - 30 \frac{(a^2 - 2\,a\,x - x^2)\, g^2}{(a + x^2)\, h_2} \right],$$

a, h, and x being as above, and $g^2 = \frac{\mathrm{I}}{\mathrm{A}}$ = the square of radius of gyration, A being the area, and I the moment of inertia of cross section.

Illustration of Method of Solution.—As an illustration, take a portion of a braced arch, Fig. 692. We have first to plot the upper curve or locus of m, for the given dimensions of the centre line of the arch. This curve once plotted, then, for any position of the weight, we have only to prolong p to m, and draw a line from m to the end of centre line, if the arch is fixed at ends, c_1 being easily found from our formulæ above. In similar manner, we draw a line from m to the other end, or c_2. Now these two lines are the resultants of the outer forces p, and by simply resolving p in these directions we have at once V and H, while the moment at the end $M_1 = -H c_1$, positive if it tends to cause compression in lower flange, or negative if it acts below the end, as c_1. We can now easily find the strain in any flange, as D, whether the arch vary in depth or not, provided only it is symmetrical with respect to its centre line. Thus, for D, take the opposite apex a as the centre of moments. The moment of H, with reference to a, as shown in the Fig. 691, tends to cause tension in D, while that of V causes compression. We have then, representing tension by the minus sign,

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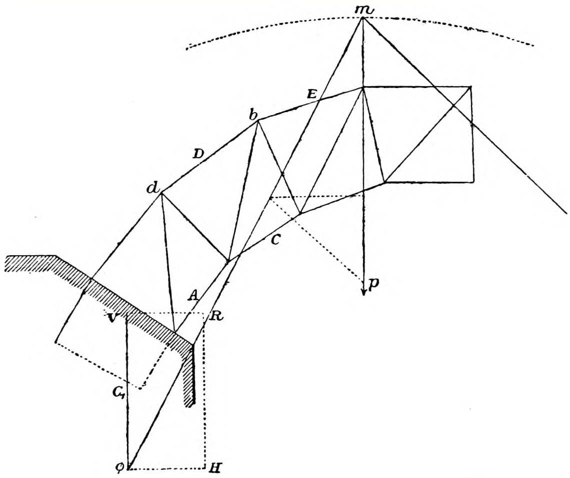


$$\text{Strain in D} = \frac{\text{Moment of V} - \text{moment of H}}{\text{lever arm of D}},$$

all with reference to a. If the result is negative, it indicates tension, if positive, compression; if it is zero, the two moments are equal, and no moment exists at a; hence a must be a point of inflection. H and V must be taken as acting at ϕ, Fig. 692. We can evidently conceive these as acting at the centre of the end cross section, if we take into account the moment $H\ c_1$. Similarly, for C we take b as centre of moments, and then, since H now causes compression in C, and V tension, we have for V and H, acting at ϕ

$$\text{Strain in C} = \frac{\text{Moment of H} - \text{Moment of V}}{\text{lever arm of C}}.$$

For V and H, considered as acting at end of centre line, we have

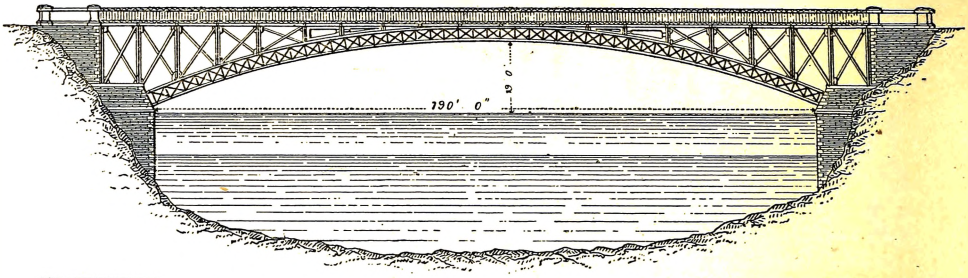
$$C = \frac{\text{Moment of H} + H\ c_1 - \text{Moment of V}}{\text{lever arm of C}},$$

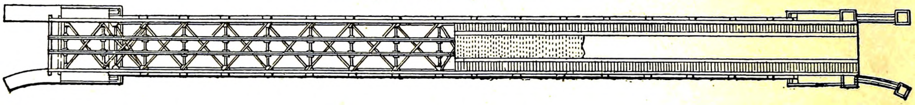
taking C, without regard to its sign, but simply to the kind of strain it tends to cause in the piece in question. As when H is below the end c_1 is negative, we should have $-H\ c_1$ for moment, causing compression in C. Thus we may proceed till we pass P, which with its proper sign, as producing tension or compression in the piece in question, must also be taken into account, or we may instead take the moments of V and H at the other end, that is, the same side of the weight as the piece itself. The diagonals may be similarly found by moments. It will, however, be best to determine them by diagram, one of the flanges, the first upper flange, being calculated in this case. They may also be calculated from the resultant shear at any apex. Thus, for diagonal 3 find the vertical components of the previously determined strains in D and C. These vertical components, together with the vertical component of the strain in 3, must for equilibrium be equal and opposite to the total shear at b. Calling this shear F, and α, β, and γ, the inclinations of D and 3, we have for the strain in 3, $S^3 = (F - S_1, \sin. \alpha - S_2, \sin. \beta) \cos. \gamma$.

If either of the vertical components of the strains in D or C acts opposite to the shear F, it must, of course, be subtracted; if in the same direction, added to F. The moment $H\ c_1$ is the moment at the fixed end, and is constant throughout the arch for any one position of the load. It causes tension in outer and compression in inner flanges, provided, as in the Fig., ϕ fall below the centre of the end section. This moment is increased, or diminished if ϕ is above, by the varying moment of H for each apex. The above method of determining the strains in the braced arch, though not strictly graphical, but rather a combination of analytical and graphical methods, offers such a ready solution of this important and difficult case, that we have not thought it out of place to notice it somewhat in detail. We consider it by far the simplest and easiest method which has yet appeared.

Bridge over the River Esk, Tasmania.—This bridge, Figs. 693 to 696, consists of a light wrought-iron arch of 190 ft. span, with 20 ft. rise from the chord line to the under side at the centre. It springs off cast-iron bed-plates which rest upon brick abutments let into the solid rock. It is composed of two arched ribs, 15 ft. apart from centre to centre, each 4 ft. deep and 20 in. wide. The tops and bottoms of these are constructed of wrought-iron plates and angle irons, connected together by radiating pieces of T iron and diagonal braces of angle iron. The roadway is laid upon a line of nearly flat girders, resting on the top of the arch at the centre, and extending to the abutments at each end, but carried between these points upon vertical wrought-iron columns, which stand on the tops of the ribs, being diagonally braced together with angle irons, together producing open spandrils of great strength. The ribs, spandrils, and railway girders are braced together in every direction, Figs. 694 to 696. The bridge is 220 ft. in length on the roadway line. The width of the platform between the handrails is 15ft., divided into a footpath of 3 ft. 6 in. on each side, and a roadway in the centre. The weight of wrought iron in the bridge is 105 tons, or under half a ton to the foot run; the weight of the cast-iron railing and bed-plates, 15 tons.

693.





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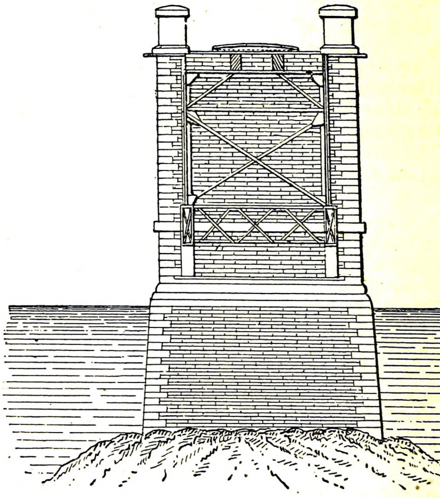

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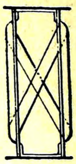


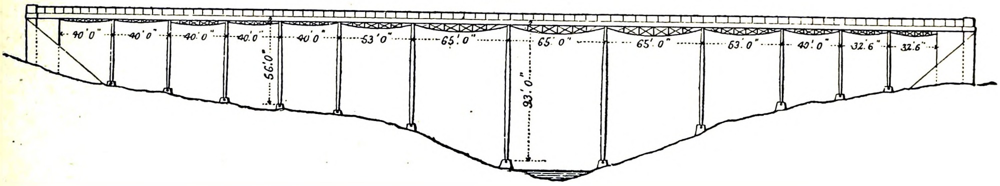
The mode in which this bridge was erected was considerably more novel than its construction. Many flat girder-bridges have been constructed on pontoons, and floated to the piers prepared for them; but there is, perhaps, no previous instance on record of an arch being so dealt with. The height of the roadway of the bridge is nearly 80 ft. above the bottom of the gorge; the depth of water is about 50 ft. at high water spring tides, and the rush of water, when the river is suddenly flooded by storms, is almost irresistible in its force. All these considerations united to make the construction of a scaffolding across the gorge impracticable, except at an enormous cost; and the engineers therefore decided to put the work together on a floating dock, carry it to its place, and deposit it on the abutments with the fall of the tide. All preliminary arrangements having been completed, the dock was swung round at high tide and secured between the abutments. At nineteen minutes to three o'clock the arch rested on its bed, and at twelve minutes past three o'clock the dock, with the scaffolding, floated from beneath, leaving the arch firmly wedged in its permanent position.

With regard to the iron work, the bows were riveted together in 12-ft. lengths, and all the other parts in equally convenient lengths for shipment, in all comprising upwards of 500 pieces, each piece composed on an average of ten pieces, the whole fastened together by nearly 24,000 rivets.

The experience gained in the Coblentz Bridge, which originally was pivoted at the abutments, would indicate that the greatest advantage is obtained by making the braced arch continuous at the crown and fixed at the ends. After the erection of the Coblentz Bridge it was considered advisable to block up the end, and thus virtually to fix the arch at the abutments.

Norwegian Railway Bridge.—Figs. 697 to 699 show the type of viaduct adopted for the Norwegian State Railway. This system, invented and elaborated by A. J. Petersson, of Christiania, admits of the spans being varied in proportion to the varying height of the viaduct, and offers many advantages as regards economy and facility of erection. Each pier, Figs. 698, 699, consists in effect of a couple of shear legs, pivoted at the upper end to the girders, and at the lower end to the masonry foundations. Expansion and contraction of the metallic superstructure thus cause only a slight inclination of the piers from the perpendicular, without inducing any bending stresses on the ironwork. The fish-bellied girders, it will be seen, can be made similar at each pier head, whatever the spans may be, and therefore the detail is simpler than would be the case, if parallel girders of depths suitable to the respective spans were adopted.

697.



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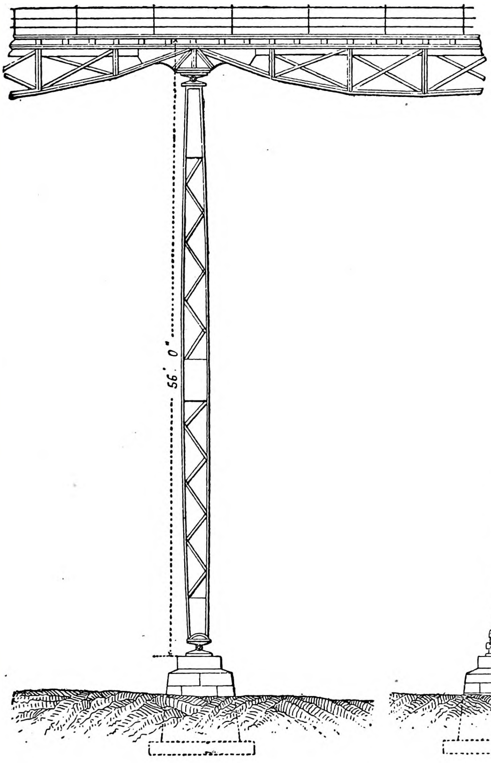

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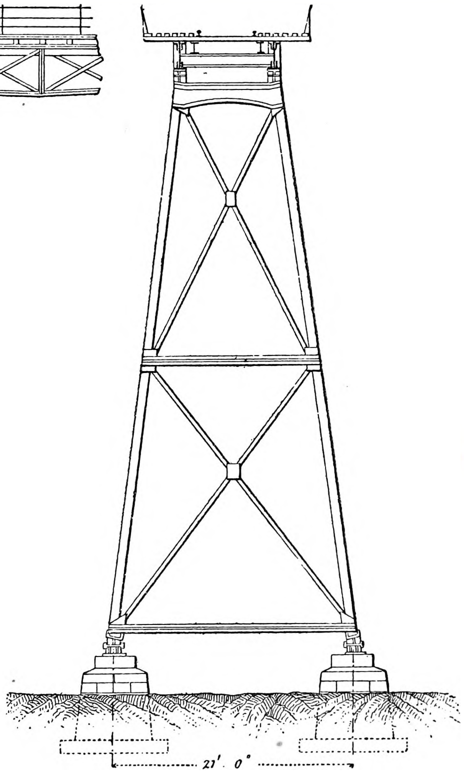


Bridges of Steel.—The use of steel for bridges and girders will before long be generally allowed, especially when those structures are of magnitude. The specific weight of steel is practically the same as that of wrought iron, but it is the much higher capability of bearing strain wherein consists its chief value, and its applicability to constructions of a size never yet attempted.

It may be admitted that 12 to 15 tons a sq. in. is a safe compressive working strain, when the material is not permitted to deflect. When in the form of a solid pillar, the strength of mild steel does not exceed $1\frac{3}{4}$ times that of wrought-iron; but this is still open to inquiry, and it would not be actually safe to adopt for steel pillars a greater load than 50 per cent. more than for a similar section of wrought iron.

The Admiralty tests for steel plates are as follows;—Tensile strain a sq. in.; lengthways, 33 tons; crossways, 30 tons. The tensile strength is in no case to exceed 40 tons a sq. in. For the hot forge test, all plates of 1 in. in thickness and under should be of such ductility as to admit of bending hot, without fracture, to the following angles;—Lengthways of the grain, 140°; across the grain, 110°

For the cold forge test, all plates of the thickness stated should admit of bending cold, without fracture, to the angle given for each thickness. With the grain; 1 in., 30°; $\frac{7}{8}$, 40°; $\frac{3}{4}$, 50°; $\frac{5}{8}$, 60°; $\frac{1}{2}$, 70°; $\frac{7}{16}$, 75°; $\frac{3}{8}$, 80°; $\frac{5}{16}$, 85°; $\frac{1}{4}$ in. and under 90°. Across the grain; 1 in., 20°; $\frac{7}{8}$, 25°; $\frac{3}{4}$, 30°; $\frac{5}{8}$, 35°; $\frac{1}{2}$, 40°; $\frac{7}{16}$, 50°; $\frac{3}{8}$, 60° $\frac{5}{16}$, 65°; $\frac{1}{4}$ in. and under 70°. The edges should be drilled or sawn, and not punched, in cutting the sample from the plate. In other respects, they should be treated as for wrought iron. Steel rivets are very brittle, and it is usual to unite steel plates with iron rivets of larger size than for iron plates.

The British Association Report, 1878, on the use of steel for structural purposes, recommends that the employment of steel in engineering structures should be authorized by the Board of Trade, under the following conditions;—That the steel should be cast steel, or steel made by some process of fusion, subsequently rolled or hammered, and that it should be of a quality possessing considerable toughness and ductility. That the greatest load which can be brought upon the bridge or structure, added to the weight of the superstructure, should not produce a greater strain in any part than $6\frac{1}{2}$ tons a sq. in. But the Committee do not limit the coefficient to this value in railway structures generally, as cases will arise where steel of special make and greater tenacity is required.

This is in accordance with the suggestion of D. Adamson, that a harder kind of steel, having a tensile strength of 40 to 50 tons a sq. in., would be better adapted to the purposes of bridge building.

H. N. Maynard, in a paper read before the Iron and Steel Institute, in 1879, states that in practice it is better to specify, in regard to the resistance of steel, that it shall be from 36 to 41 tons a sq. in. in tension, with a contraction of area between 35 and 45 per cent., and elongation of 15 per cent. in 8 in., and that it shall bear punching a $\frac{3}{4}$-in. diameter hole, $\frac{3}{8}$ in. from edge, without injury.

Working upon this specification, the results are verified by the following seven examples taken from inspection reports;—

No. 1 Test.—3 in. by 3 in. by $\frac{3}{8}$ in. Breaking strain a sq. in., 41·095 tons. Reduction of area, 43 per cent.; elongation in 8 in., $1\frac{3}{4}$ in.

No. 2 Test.—4 in. by 3 in. by $\frac{3}{8}$ in. Breaking strain a sq. in., 39·304 tons. Reduction of area, 34 per cent.; elongation in 8 in., $1\frac{5}{8}$ in.

No. 3 Test.—8 in. by $\frac{3}{8}$ in. bar. Breaking strain a sq. in., 40·469 tons. Reduction of area, 34 per cent.; elongation in 8 in., $1\frac{7}{16}$ in.

No. 4 Test.—8 in. by $\frac{7}{16}$ in. bar. Breaking strain a sq. in., 38·125 tons. Reduction of area, 34 per cent.; elongation in 8 in., $1\frac{3}{4}$ in.

No. 5 Test.—7 in. by $\frac{1}{2}$ in. bar. Breaking strain a sq. in., 38·379 tons. Reduction of area, 52 per cent.; elongation in 8 in., $1\frac{3}{4}$ in.

No. 6 Test.—Plate $\frac{7}{16}$ in. thick. Strain a sq. in., 38·006 tons. Reduction of area, 46 per cent.; elongation in 8 in., $1\frac{13}{16}$ in.

No. 7 Test.—Plate $\frac{1}{2}$ in. thick. Strain a sq. in., 39·400 tons. Reduction of area, 45 per cent.; elongation in 8 in., $1\frac{13}{16}$ in.

Such material may be fairly used at a much higher strain than that hitherto used for iron.

For bridges of large span, or over 200 ft., lightness is one of the most important considerations, for smaller spans this consideration is of less importance.

Having in a design for an iron bridge allowed for safety the usual margin of strength, it does not follow, if steel is taken at less than double the price of iron and capable of bearing double the strain that iron bears, that a cheaper structure is obtained, because the steel cannot be used throughout at half the thickness of the former, on account of the risk of some parts buckling and of corrosion rapidly destroying thin sections; but, with a suitable combination of steel and other material, a structure cheaper than all iron or all steel is obtained. With a girder of the Warren type, for a bridge 120 ft. span with a road at the bottom of the girder, and using for iron the Board of Trade data of 4 tons a sq. in. of section, the sectional area required at the centre is 41 in.; and at the end $12\frac{1}{2}$ in.

Constructing this girder in the usual way, and adopting a form of the top flange calculated to resist compression, it gives at the centre a section made of top plate 24 in. by 1 in., two sides of 12 in. by $\frac{1}{2}$ in., and two angles equal to 5 sq. in., giving in all the required 41 sq. in of sectional area.

Dealing with the end section, and building a section that will join on to the ends of the former, it must be shaped to correspond, and the thickness only must vary; therefore we should have a section which has the top plate only $\frac{3}{16}$ in. thick, and the sides and angles of $\frac{1}{4}$ in. thick, producing the required sectional area of $12\frac{1}{2}$ in. These thicknesses are, however, too small in practice, and it becomes necessary to use a section which has $\frac{5}{16}$-in. plate on the top, and the other parts $\frac{3}{8}$ in. thick, making together a sectional area of 20·7 in., or 8·2 in. of section more than is required.

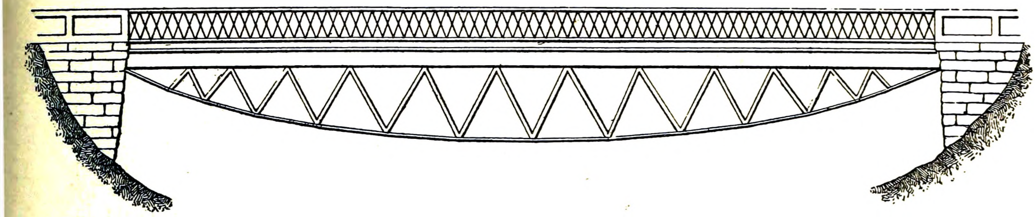
Proceeding in a similar way to build with steel, having, say, double the strength, or 8 tons, as the data, instead of 4 tons for iron, at the centre we may make a section, using the same external dimensions, but half the thickness, without any practical difficulty; but towards the ends of the girder, the strain requires a section somewhat less than $\frac{1}{8}$ in. thickness, and becomes practically useless, so that there is the necessity of adopting the most practical section, containing 20·7 in. of area where only $6\frac{1}{4}$ in. are required, the latter being 14 in. in excess of what is necessary to meet the strain at that part.

Therefore, while suitable steel remains at a higher price a ton than iron, there is a disadvantage in using all steel in such a bridge, on the score of economy.

In order to overcome this difficulty, H. N. Maynard has recently constructed steel bridges, having a combination of materials so arranged as to meet the strains and give the desired results in the following manner; The proportion of steel being about half the total weight, the remainder is made up of the best Lowmoor or Yorkshire iron, capable of bearing a slightly increased strain over that of ordinary iron, the result being less costly than either all iron or all steel.

The bridge, Fig. 700, was designed by Major Adelsköld to meet very peculiar conditions. The distance to be spanned was no less than 137½ ft., and this not only over a violent stream, but just at the point where a torrent begins to fall over a ledge of rock of great height. It was out of the question to think of erecting any intermediate support. In order to throw the bridge across, it was necessary to lift the girders over bodily, and they were therefore made as slight as possible. Iron was rejected as the material of construction, and puddled steel from the works of Surahammar, in the north of Sweden, was employed. The bridge was constructed at Bergsund's Works, at Stockholm. The dimensions were calculated for a working strain of 8 tons an inch, every portion having been tested to 16 tons a square inch before being put in position. The total weight of the structure was barely 50 tons. An iron bridge of the same dimensions would not have weighed much less than twice this amount, and its cost would have considerably exceeded that of the steel bridge. The method adopted to throw the girders across the fall was very simple. Two large derricks were erected, one at each side of the torrent; each derrick consisted of two spars set, one up, the other down stream, resting on the foreshore at the foot of the abutment, and lashed together at top. Guy ropes extended back from these spars to anchoring stakes driven into the ground; by these the derricks were supported as they leant far over the stream below. A cable was passed from the end of each girder, through blocks suspended from the derrick, at the opposite side of the entrance, and by hauling on this the girder was partly raised and partly hauled across to such a distance that the other derrick could take firm hold of the remaining end of the girder. Nothing then was required but to raise the girder and drop it into its place.

700.



The Saint Louis Bridge.—The finest specimen of a steel bridge is to be found in the St. Louis Bridge. This great engineering feat of bridging the Mississippi at St. Louis occupied six years, and is probably unrivalled.

The clear width of the river spanned by the St. Louis Bridge is 1622 ft., and this space is divided into three openings by two piers, occupying together 108 ft., leaving a clear span for the centre arch of 520 ft., and for the side arches of 502 ft. The rise of the centre span is 51 ft. 6 in., and of the side ones, 47 ft. 10 in.

The execution of suitable foundations for the two river piers, one 145 ft. and the other 174 ft. in height from the rock to the under side of the roadway, was a work of great magnitude, increased by the difficult nature of the bed of the river, and the violent scouring from the under-currents constantly taking place, and shifting the positions of the sand overlying the rock.

The dimensions of the base of the eastern pier are 82 ft. by 60 ft., and the western pier is 82 ft. by 40 ft., and both were sunk in caissons through 78 ft. and 50 ft. of sand respectively. These caissons contained air chambers 9 ft. in height, the area of the chambers being equal to that of the under side of the pier, and the latter was divided into three compartments. The caissons are built up of timbers and iron girders, the roof being made of ample strength to support the whole mass of masonry above it, as described at p. 208 of this Supplement.

Both abutments were also built on caissons. The height from the under side of the foundation to the top of the cornice is 196 ft. 9 in. on the eastern side.

The cubic contents of this abutment is 11,860 yards, while the east abutment has 22,453 cubic yards, and the east pier 13,240 cubic yards.

Altogether the total amount of masonry in the structure is 103,000 cubic yards, namely, 10,000 yards of sandstone, 12,000 yards of granite, and 81,000 yards of magnesian limestone.

The tubes which support the bridge are all made of crucible cast steel, and are built up in lengths, each length being formed of six staves accurately fitting at the joints, and forming a circle 17½ in. diameter. These staves are then enveloped in steel ½ in. thick. The staves were tested for compression to 60,000 lb., and for tension to 40,000 lb. a square inch, without permanent set, and the envelope was tested for compression and tension to 40,000 lb. a square inch without set, the ultimate tensile strength of both staves and envelopes being set at 100,000 lb. a square inch. The lengths of tubes are connected by steel couplings, which contain the necessary provisions for the attachment of the different systems of struts and braces.

The width of the upper or road platform is 75 ft., and gives accommodation to two spacious footpaths and four lines of tramways, while the lower platform carries two lines of rails.

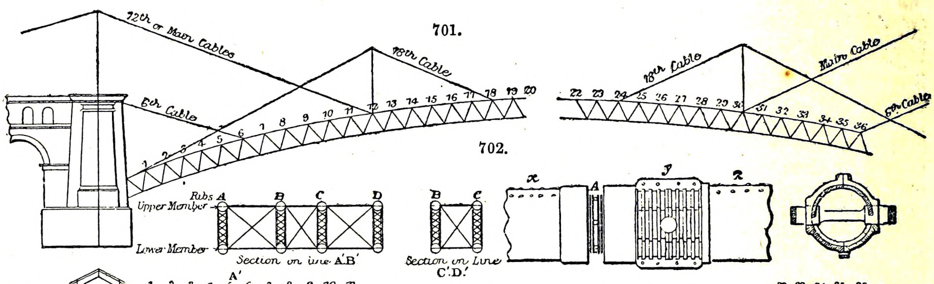
The prominent feature in the erection of this bridge was the absence of scaffolding in the river, except for a short distance adjacent to the piers and abutments.

The bed-plates upon which the skewbacks rest, were bedded into the masonry during the building of the piers and abutments. After the skewbacks and their connected tubes were hoisted into position upon the bed-plates and anchor bolts, and firmly screwed down to the bed-plates, measurements and observations were made to ascertain the amount and direction of variation from correct position.

From these, the amount and direction of the changes necessary to bring each skewback and its connected tube into correct position, were determined. The changes necessary to correct the errors shown were made by cutting out the holes through which the anchor bolts pass, and allowing the higher skewback to drop the proper amount. The angular changes needed to correct both horizontal and vertical deviations, were made by inserting between the skewback and its bed-plate angular plates.

Each span is composed of four arched ribs, respectively 16½ ft., 12 ft., and 16½ ft. apart from centre to centre, Fig. 702, in which the two diagrams to the left are sections through **A B** and **C D**, Fig. 703, respectively. Each of these ribs is composed of two lines of tubes 12 ft. apart between centres of the tubes. The tubes are about 12 ft. long. The upper and lower members of each rib are connected together by a system of triangular bracing. The first or skewback tubes of each member are screwed into the large wrought-iron skewbacks, which in turn rest upon the bed-plates set into the masonry; the whole being anchored to the piers or abutments by large steel anchor bolts. The tubes forming one line or member are rigidly connected at their ends by grooved couplings, Fig. 702, fitted to grooves cut on the ends. The couplings are made in halves with flanges; through the centre of each and the ends of the tubes passes a taper pin-hole for the steel pin, upon which the braces and cross stays are attached.

Many particulars, which were afterwards carried out in the construction of this bridge, are given in the description of Roebling's system, at p. 702 of this Dictionary.



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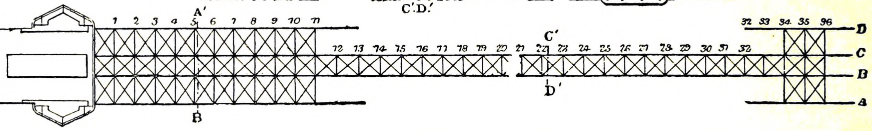


703.

Starting from the skewback tubes, all four ribs were simultaneously erected as far as the tenth or eleventh tubes, Fig. 701. Here the outer tubes were discontinued, and only the two inner ribs carried to the centre. The ribs were connected and stiffened by their connecting struts and tension rods. At the central panel, these long semi-arches presented a rectangular cross section as at C D, Figs. 702 and 703, about 12 ft. deep and 12 ft. wide.

The standard of temperature to which the computation and measurements were referred is 60° Fahr., and the curve of the finished arch, under its permanent load at this temperature, was taken as the normal curve of the arch. The insertion of the tubes in the first span was the most difficult. For this span, two sets of tubes were prepared; one *z* similar in construction to those composing the arches, and made of the exact calculated length of the central space; the other *x* differing from these only in that they were fitted with an internal adjustable screw, by means of which the tubes could be lengthened or shortened to a limited extent, in case there should be found any errors in the measurements of the span. Fig. 702.

The screws in the adjustable tubes were made from forged wrought-iron rings 18 in. long, 15 in. outside, and 11 in. inside, diameter. The screw thread was right and left handed on the different ends, square, and $\frac{3}{16}$ in. deep; the pitch was $\frac{3}{8}$ in. In the cylindrical part of the screw between the right and left threads, six holes 1½ in. in diameter were bored, for the purpose of passing rivets to fasten the steel rings, which were to fill space A, Fig. 702, after the tubes were screwed out to proper length, to make a solid steel connection throughout the tube. The screws had been prepared of this form, with the expectation that they would only be needed to lengthen or shorten the tubes before they were inserted; the forcing apart of the arches with these screws had not been anticipated. They fitted well, and required a moderate power to turn them, even without any pressure against the threads; and with any strain of either compression or tension upon the tubes it became very difficult to move them. After the inner ribs were connected the cable strains were reduced so that there was only about 160 tons strain on the main cables. Then the erection of the outer ribs was going on, and this threw the additional weight of these outer ribs upon the inner ribs. Efforts were made to turn out the screws in the first arch by means of bars inserted in the holes of each screw, connected at the ends in a wheel form. But slow and slight progress was made, as the bars were constantly broken. The tubes, fastened at both ends by their couplings, were subject to strains of compression and tension as the temperature varied. Only at the interval when these strains were zero could any result be obtained in moving the screws. To determine when this occurred was only possible by keeping a constant strain upon the bars. The great labour and slow progress led to two improvements which overcame the difficulty in the remaining parts of the arches. First, one end of the central tubes was left free by making a pin-joint only. By this means no tension could be got on these tubes, and any opening or relaxation of compression at this loose joint, produced by contraction or expansion of the arches, according as it was a lower or upper tube, could readily be taken advantage of to set out the screws. The second improvement was the designing of a wrench to turn these screws, even under a high compressive strain. These wrenches were made of railroad iron, and resembled in form an elongated letter A. Each foot was fitted with a T-shaped nipper, sufficiently narrow to enter the opening A, Fig. 702, between the bands of the tubes, which in some cases was only $\frac{5}{8}$ in. This wrench was about 7 ft. long, and acted by direct shearing strain upon a $1\frac{1}{2}$-in. steel pin, passing through the screw and projecting sufficiently at each side for the nippers to catch it. With the use of the wrench, the power of six men on a double-geared crab, could be transmitted through a sixfold purchase to the end of the wrench.

It would be quite possible to remove any part of the arches of this bridge, without the use of cables above, or false work beneath. For instance, a tube could be removed and another inserted, with no risk to any part of the structure, and but partial interference with the traffic, by suspending the rib from which the tube was to be taken upon the adjacent ribs by means of diagonal suspension rods. The adjustable screws could then be relaxed sufficiently to relieve the respective members from tension and compression, the rib disconnected at any point, and a new tube inserted. The temperature at the time should be considered, and all means taken to hold the rib in its position by struts and tie-rods, in order that it may not move from its proper place, and thus prevent or delay the insertion of the new tube. If all material were previously prepared, the whole operation would perhaps be possible within twenty-four hours. After the completion of all the ironwork on Span I. and most of the woodwork of the upper roadway, two tubes in the lower members of ribs which had been injured during the erection, were removed and new ones inserted. At this time these ribs were practically loaded with their full permanent load, and were unsupported by any cables.

The removal of a skewback tube would be more laborious, but still possible. These tubes being screwed into the skewbacks, it would be necessary to remove another tube first in order to obtain working room; it would be comparatively slight labour to remove any other part of the arches.

The tubes as well as all other pieces of the bridge were painted on all sides before they left the shops, but the interior of the tubes, and their joints, were thoroughly painted after the tubes were in place, by using a small spindle-shaped vessel such as would pass freely down the tubes beneath the steel pins, about 4 in. by 5 in., perforated at the top and sides with fine holes, its bottom filled with lead, the whole set upon rollers, and fastened by a movable joint to a gas-pipe in 12-ft. pieces. This apparatus was first forced down the whole length of the tubes, joint by joint, until it reached the skewback, and then attached to a force-pump by flexible hose, and thin asphaltum varnish forced down the pipe. A steady spray of the paint was projected against the top and sides of the tubes, and the surplus ran down along the bottom; the pipe was slowly withdrawn, the pump being kept at work. This sprinkler was replaced by a simple gas-pipe, closed at the end and perforated on all sides with numerous fine holes, their aggregate area being proportioned by experiment to the capacity of the pipe, which was 1 in. in diameter. This method was wasteful; but it allowed the mixture to penetrate the joints of the staves, screws, and backing, and protect them from the attack of water, to which they would be most exposed, should there be any leakage or condensation within the arch tubes.

A 30-ton locomotive at different positions of the centre span produced these results on Rib B.

Engine at	Deflections in Inches.		
	At Joint 11.	At Centre.	At Joint 33.
West Quarter, Joint 11	0·516	0·12	−0·06
Centre of span	0·216	0·6	0·12
East Quarter, Joint 33	−0·024	−0·012	0·72

Similar observations were made at other points. The same load at different points produced the following results;—

Engine.	Deflection in Inches at Centre of		
	Span I.	Span II.	Span III.
At centre of each span	0·636	0·6	0·636
Moving 5 miles an hour	0·5	0·42	0·5
„ 10 „ „	..	..	0·75
„ 15 „ „	..	0·75	..

Different loads, at different points, cause the deflections recorded in the following table;—

Load, allowing 15 tons for each Tender.			Deflection in Inches at Centre of			
Loco-motives.	Weight in Tons.	Placed on Middle of	Rib A.	Rib B.	Rib C.	Rib D.
7	334	South Track of Span III.	2·48*	1·84*	1·33†	0·83
7	334	,, ,, ,, II.	2·8*	2·15*	1·37†	1·1
7	350	,, ,, ,, I.	2·48*	1·8*	1·27†	0·82
14	334 350	North ,, South ,, } Span I.	3·048	2·892	2·616	3·
14	334 350	North ,, South ,, } ,, II.	3·48	3·44	3·89	3·92
10	492	,, ,, ,, II.	2·37	..	..	..

* Loaded rib. † Rib partly loaded.

The greatest vertical deflection of Span II. when one-third was loaded with locomotives was 1·43 in. and at the fourteenth joint; when one-half was loaded this maximum deflection was 1·67 in. and at the fourteenth panel, and when five-eighths was loaded, it was 2·25 in. and at the seventeenth panel. The greatest negative deflection or rise of the same span when 12 of the 44 panels were loaded was 0·63 in. and at the twenty-ninth joint. With a load of 334 tons on north track of Span I., Rib C of Span II. raised 0·3 in.; on south tract of Span II., Rib B of Span I. raised 0·12 in.; on south track of Span. I., Rib B of Span II. raised 0·216 in.; and with the same load moving eastward over Span I., Rib B of Span II. raised 0·48 in.; in each case the measurement being at the centre of the rib.

After each test the load was entirely removed and observations made for permanent set, which, however, was not at any time visible, nor was any side deflection of the outer ribs under the various loads discovered.

It should be carefully noted that steel does not work so freely and easily as wrought iron. It will not stand the same amount of forge and smith work, unless the operations be conducted with greater care than is required in the case of iron. If steel be overheated, it is difficult to make a good weld. Iron rivets are frequently used with steel girders. Tempering steel in oil has the effect of increasing both its toughness and limit of elasticity. It increases the latter quality to three times that of wrought iron, a most important consideration. The relative ultimate strength of materials is not the only point to be attended to by engineers. A material which, by its large range of elasticity, gives ample warning before it undergoes final rupture, is to be preferred to one which may possess a greater ultimate strength without the other valuable quality.

See CARPENTRY, CALCULUS, DREDGER, PILE DRIVER, STRENGTH OF MATERIALS, VIADUCT.

List of Books on BRIDGES.—Baker (B.), 'On the Strengths of Beams, Columns, and Arches,' 1870. Cargill (T.), 'The Strains upon Bridge Girders,' 1873. Rankine, 'Civil Engineering,' 1877. Rankine, 'Applied Mechanics,' 1877. Dubois, 'Graphical Statics,' 1877. Fenwick, 'The Mechanics of Construction.' Hurst, 'Tredgold's Carpentry,' 1875. Bow, 'Economics of Construction,' 1873. Bashforth, 'Construction of Oblique Bridges,' 1857. Hart, 'Bricks.' 'Roorkee Treatises on Civil Engineering.' 'Professional Papers on Indian Engineering.' 'The Engineer.' 'Building News.' 'Engineering Journal of the Society of American Engineers.' Haskoll, 'Examples of Bridges.' Mattheson, 'Works in Iron,' 1877. Tarn, 'The Science of Building.' Young, 'Strains upon Girders and Arches.' Fairbairn, 'Cast and Wrought Iron Construction.' Barlow, 'Strength of Materials,' 1867. Clark, 'The Pesth Bridge.' Kirkaldy, 'Iron and Steel,' 1864. 'Minutes of the Proceedings of the Institution of Civil Engineers.' Wood, 'Construction of Bridges and Roofs.' 'Transactions of the Society of Engineers.' 'Annales des Ponts et Chaussées.' Cotton, 'Manual of Railway Engineering,' 1874. 'The Builder.' Whipple, 'Bridge Building,' 1873. Shreive, 'Strength of Bridges and Roofs,' 1873. Chanute and Morison, 'The Kansas City Bridge,' 1870.

CAGES.

The vehicles employed for conveying the loaded tubs from the bottom of the shaft to the surface, and the empty tubs from the surface to the bottom, are called cages. They are made of wrought iron, or steel, and should be so constructed as to carry the largest number of tubs with the least weight of cage. A cage should be compact, so as to be easily guided in its ascent and descent of the shaft, and it must be so arranged that the tubs can be readily entered and removed.

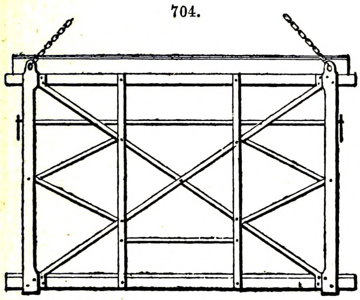
The form of a cage will therefore be determined, first, by the form of the division of the shaft in which it has to travel, and secondly, by that of the tubs it has to contain. Both of these being rectangular, it follows that the cage will always have the same form. Its dimensions and carrying capacity will evidently be determined, first, by the amount of the output at the mine and the size of the shaft, and secondly, by the power of the winding engines. Cages are generally constructed to carry two tubs, placed end to end; but where the space in the shaft is restricted, the tubs may be placed on separate floors, one above the other. Cages are known as single, two, three, or four-decked, according to the number of floors they contain. Where the output is large, cages of as many as four decks are employed, especially at the coal mines of Belgium, which carry two tubs on each floor. The floor of the cage should be provided with rails, to facilitate the running in and out of the tubs; and the openings which are left for this purpose, and which are always situate in the shorter sides of the rectangle, should be closed by some kind of self-acting catch or hook, in order to keep the tubs in position during the time of their being transmitted from the bottom of the shaft to the surface, or from the surface to the bottom. The best fastening for this purpose is one which acts by its tendency to maintain a perpendicular position.

Guides are always used in conjunction with cages, in order that the latter may maintain a regular motion in the shaft, and thus prevent those accidents which often occur with other systems of winding, by the corves or kibbles coming in contact with each other in the shaft. When rigid wooden, or iron, guides are used, the guide cheeks are placed in the centre of each of the shorter sides of the cage; they are formed of sheet iron, and should be slightly bell mouthed at each end, so as easily to slip over slight inequalities. With flexible wire-rope conductors, rings are provided, at the top and bottom, at each of the angles of the cage. The top of the cage should be provided with an iron bonnet or roof, for the protection of persons riding in it. The cage is suspended from the winding rope by short chains at each of the upper corners, and, in the case of heavy cages, from the middle of the longer sides as well.

A wide margin of strength must necessarily be allowed in drawing cages, and the parts should be strongly put together. The dead weight of the cage is therefore very considerable, and constitutes an important item in the load to be raised. This dead weight should be reduced as much as possible, while at the same time preserving the strength and rigidity of the cage. Wrought-iron cages weigh from 5 to 6 cwt. when designed to carry a single tub, and from 9 to 10 cwt. when the carrying capacity is two tubs, whether the cage be a single or a two-decker; while a two-decker cage, constructed to carry four tubs, will weigh from a ton to a ton and a quarter, or even more. To reduce the dead weight of the cage, steel can be substituted for wrought iron.

Figs. 704, 705 show a design for a single-decked wrought-iron cage, to carry two tubs; Figs. 706, 707 a two-decked cage, to carry four tubs; and Figs. 708, 709 a four-decked cage, to carry four tubs.

704.



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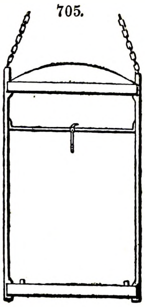

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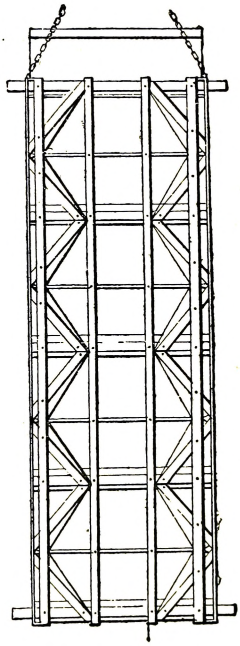

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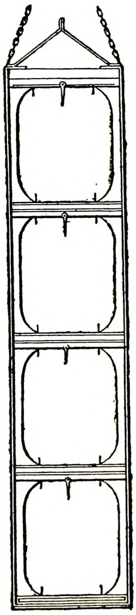

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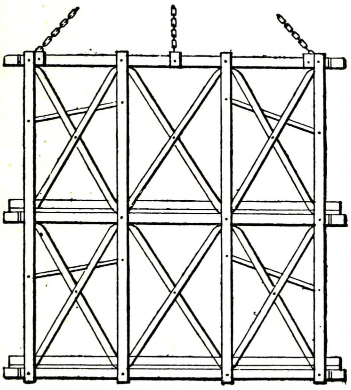

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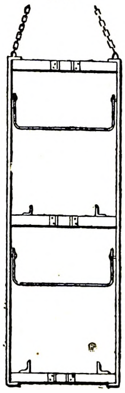


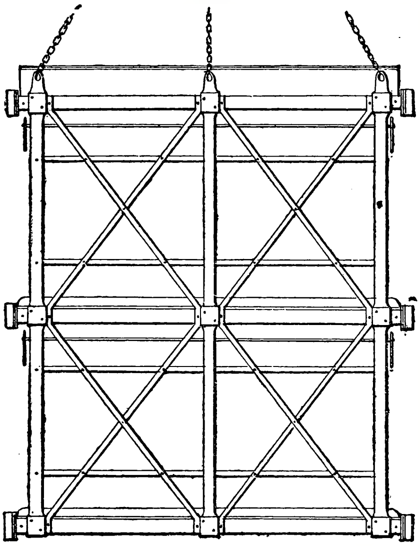
Figs. 710, 711 are of a two-decked steel cage, to contain four tubs; Figs. 712, 713, a two-decked steel cage, to carry two tubs, and to be used with wire-rope conductors.

The guides, or conductors, in general use consist of lengths of timber, usually of Memel pine, which are placed vertically in the shaft, and held in position by being firmly bolted to cross timbers, called buntons, which are placed at regular intervals throughout the depth of the shaft. These buntons are also of pine, and they are firmly fixed into the masonry of the shaft, at intervals of about 6 ft. The sectional dimensions of the cross pieces are about 9 by 3 in., and the guides about 4 by 3 in.

The system of guides practically divides the shaft, or that portion of it which is set apart for drawing purposes, into two compartments, in one of which the loaded cage ascends, while in the other the empty cage descends; the arrangement of the guides may be varied in many ways, according to the requirements of the case. Generally only two guides are used to each cage, one on each side, and these should be placed in the centres of the ends, or shorter sides, for when in this position they impart the greatest amount of steadiness to the cage. The guides must, of course, extend throughout the whole of the distance traversed by the cage; they reach down to the floor of the levels entering the pit eye, and they should rise to the distance of a few feet above the mouth of the shaft. When the guides are fixed in the middle of the shorter sides of the rectangular space in which the cage moves, and when, as is usually the case, the tubs are run off and on at those sides, it becomes necessary to work without the regular guides at the points where the cage is loaded and unloaded, and to provide an arrangement by means of which it may be guided on the other sides.

In some cases bridge rails, and in others angle iron, are used instead of wood for guides; but whatever the material employed may be, it is essential that the guides be regular in section, and the joints between the several lengths evenly and firmly made. Iron will, however, in consequence of its comparative want of elasticity, cause a greater amount of jolting in the cage than wood, and this is a matter of some importance, especially in rapid winding.

710.



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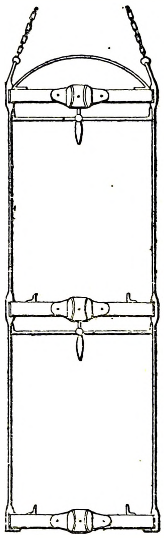

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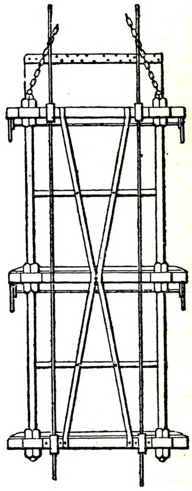

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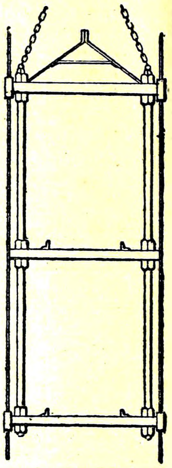


In Lancashire, and other English mining districts, the guides, or conductors, as they are more commonly called, consist of continuous round bars of iron. These are fixed to stout balks of timber at the bottom of the shaft, and are then firmly screwed to other balks situate at the top of the head frame; the cages in these cases being provided with rings to run upon the rods, instead of the ordinary guide cheeks. In many places wire-rope conductors have been substituted for these iron rods. They are generally secured in the shaft in the same manner as adopted for the rods; but sometimes only the upper ends are screwed to the balks, the lower ends being passed through holes in the timbers, and heavy weights attached to their free ends. The advantage of this method is, that the guides are kept taut by the weights, and do not therefore require the constant supervision and screwing up which they otherwise would.

The relative merits of rigid and flexible guides constitute a disputed question among mining engineers. The principal defect of flexible guides lies in the swaying motion which is set up in them and in the cage, especially when the velocity in the latter is high and the depth of the shaft great. This swaying motion may be in a great degree neutralized by the employment of four ropes or lines of conductors, but on account of want of rigidity, extra space should be allowed in the shaft, between the ascending and descending cages. To ensure safety, they should not be allowed to pass each other more nearly than 9 in. when moving in straight lines.

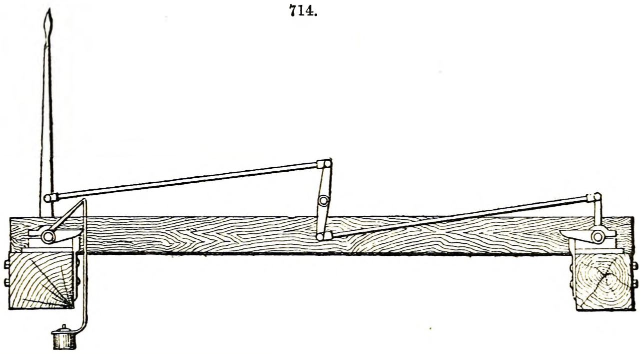
Keeps or keps consist of a series of catches, arranged over the mouth of the shaft, and by means of which the cage is supported during the time that the loaded tubs are being run off, and the empty tubs run on. They project slightly over the mouth of the shaft, and are so arranged as to be lifted by the ascending cage, but being weighted they fall back into their proper positions directly it has passed: the cage is then lowered on to them, and the operations of unloading and loading are commenced. When the cage is ready to descend again to the bottom of the shaft, it is first raised a short distance above the keeps, and these are then lifted out of the way of the cage, by means of a series of levers to which they are connected. These levers are generally attached to a handle and worked after the manner of a railway switch, but they are sometimes arranged to be worked by the foot. The keeps being raised clear of the shaft, the cage descends, and as soon as it has passed the keeps, they are allowed to fall back to their proper positions.

A system of keeps may be contrived in a variety of ways; simplicity of construction and strength of parts being the only essential conditions in a design of this nature. One of the most simple forms of keeps is that in Fig. 714; while Fig. 715 is of another arrangement in which the catches are kept in position by springs instead of counterweights, but this is not a good plan, as springs are more liable to fail in their action than weights.

It may be remarked here, that when the cages possess more than one deck or floor, the operations of raising and lowering upon the keeps have to be repeated for each of the levels; and that the arrangements at the bottom of the shaft are similar to those at the top. To avoid this repetition, however, the arrangements sometimes include a series of stages at the mouth of the shaft, and inclined planes at the bottom of the pit, by means of which the loading and the unloading of the cages may be carried on at the different levels at once. This is especially the case in Belgium, where four-decked cages are not uncommon.

The accidents which occur in winding operations are chiefly due to one of two causes, either the breaking of the winding rope, by which the cage is precipitated to the bottom of the shaft, or the drawing of the cage over the head-gear pulley by overwinding; and both of these accidents are often attended with fatal consequences. In order to reduce these accidents as much as possible, a large number of inventions have been brought forward during the last quarter of a century; but though much ingenuity has been exercised in their construction, no perfectly satisfactory apparatus has at present been introduced.

714.



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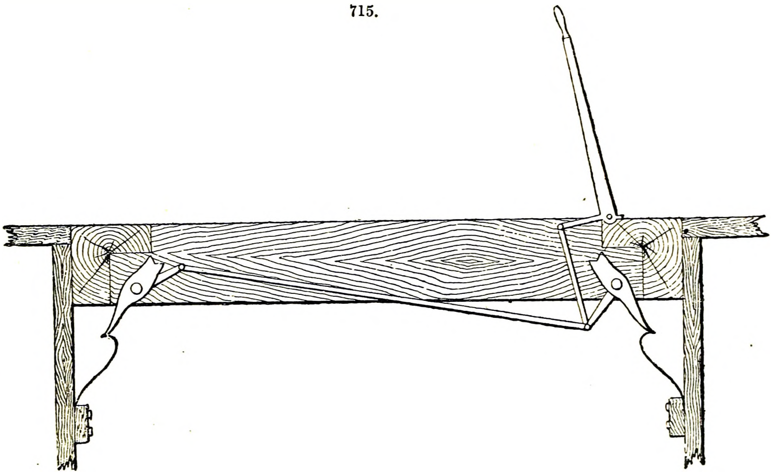


These apparatus are of two kinds. The first, which are intended to prevent the accidents which arise from the breaking of the rope in the shaft, are called safety cages; while those which are designed to prevent the fatal consequences of overwinding are called safety hooks or catches.

In safety cages the means adopted for preventing the descent of the cage in the shaft, though differing considerably in detail, are essentially the same in principle in all. They consist of a series of clutches or eccentrics, which are caused to grip the guides immediately on the severance of the winding rope, but which are kept from contact with the guides so long as the cage remains attached to the rope. It will thus be seen that the safety of the apparatus depends upon the friction exerted by the clutches upon the sides of the guides; and this friction is often so great as to completely destroy the guides, where these latter are of wood.

Against the use of all kinds of safety apparatus there exist two great objections; for the adoption of any self-acting apparatus of this kind will often be found to cause a gradual falling off in the care and attention of the men, not only in the working of the machinery, but also in the examination and care of the winding ropes and other parts of the apparatus, the whole safety of the working being left to depend upon the proper action of the safety appliances, which may themselves fail at the very moment when required. Besides the danger arising from this carelessness induced by a feeling of security, the apparatus itself introduces another element of danger into the working of the pit; for, if it is not frequently examined and kept in proper repair and working order, it will be apt rather to occasion than to prevent accidents, by causing the cage to stick in the shaft, or otherwise interfering with its working. These appear to have been the opinions held by some members of a committee appointed by the North of England Institute of Mining Engineers, in 1868–70, to investigate as to the value of safety cages and hooks.

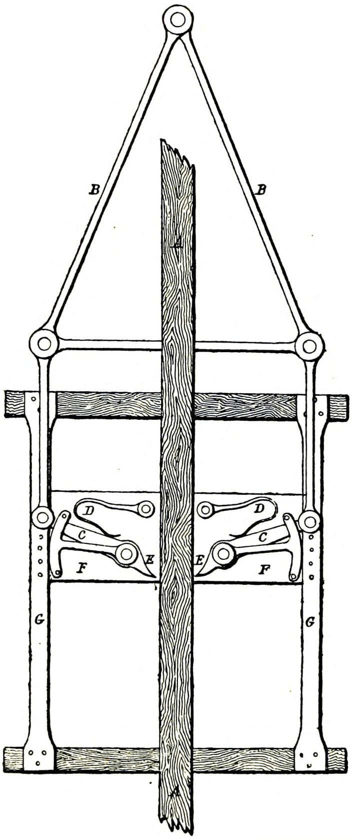
Various statements were, however, made by this committee as to accidents in which the safety appliances had proved of value, showing in such cases the action of the apparatus.

Previous to 1869 there had been at the Vach, Garth, and Wyndham pits, two broken ropes. On the first occasion the cage was 40 yards from the bottom of the pit, with two full tubs of coal, which together with the cage weighed 45 cwt.; the cage fell about 7 or 8 ft., while the levers of the safety catches grazed the conducting rods, but no other damage was done. On the second occasion, the engine driver wound the cage up to the pulley and broke the chain, when the apparatus came into operation and no damage was done. On another occasion, four men were in the cage being drawn up the pit, the rope broke, the catches ploughed the wood guides for about 4 ft., and then held the cage fast, till the men were wound up by a capstan rope. An experiment was made by kepping the cage and allowing six yards of slack rope on the pit side of the pulley, and then knocking the cage off, it slipped down 12 in., and was held firmly. The experiment was varied by allowing the slack rope to be on the drum side of the pulley, the slack rope over the pulley prevented the catches from taking firm hold of the rods, and the cage with the tub, weighing altogether 20 cwt., fell till suspended by the rope, the guides being split more or less the whole distance. On one occasion, while winding coal, one of the side chains broke, and the cage was suspended without much damage to the guides, which did not require changing. On another occasion, while winding water, when tank and cage, about 40 cwt., emerged from the sump, one of the side-chains broke, the catches slipped about 4 ft., and cut the guides nearly through, and split and otherwise damaged them, so that they had to be replaced for about five yards. Again, a bridle chain broke at one of the Wyndham pits, the lever entered the conducting rod and stopped the cage, which fell about 12 in., causing no damage.

With Ormerod's disconnecting hook at Bunker Hill Colliery, the brakesman took up the cage to the pulley with three men in, the cage was caught, and the men were uninjured; on another occasion, the descending cage was allowed to go down too quickly, and the ascending one ran up to the pulley, when the rope was disengaged, and the cage suspended.

Although this report includes mention of several other systems, and other applications of the systems named, the prevailing statement is that no practical occurrence has enabled the Committee to form an estimate of the value of the apparatus.

716.



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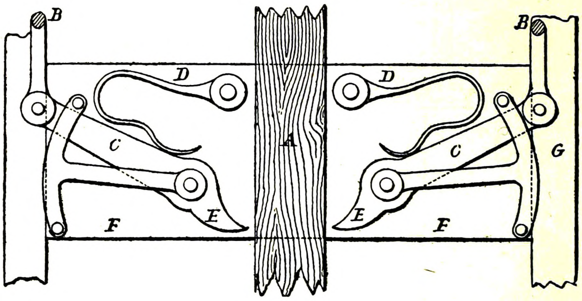

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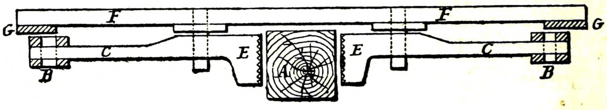

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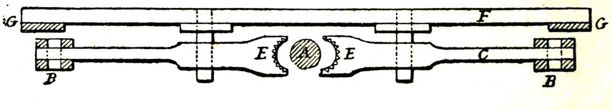
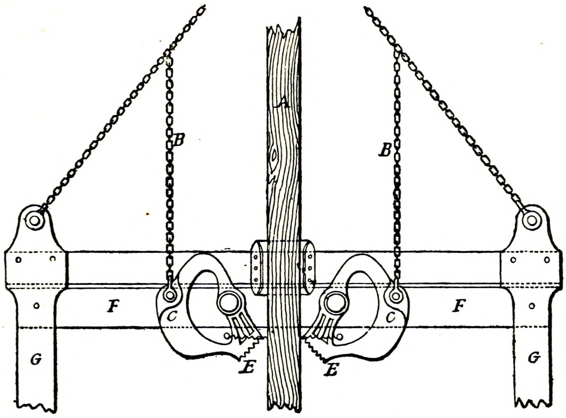


Owen's safety cage is shown in Figs. 716 to 719. Fig. 716 is a side elevation, showing the manner of attaching the apparatus to the cage, and Figs. 717, 718 are enlarged views of the details; while Fig. 719 shows the shape of the jaws of the levers as adapted for use with wire-rope conductors. A are the guides; B are the suspending rods; C levers to which the suspending rods are attached, and which, when the weight is carried, keep the levers E from coming in contact with the guides;

D are springs for giving motion to the levers C and E when the rope breaks. F is a wrought-iron plate fixed to the side of the cage, and to which the apparatus is attached; and G is the framework of the cage. Upon an examination of the figures it will be seen, that when the suspending rope breaks, the springs D will force the levers E against the guides, and the cage will remain suspended. Every time the cage is on the keeps, both at the top and bottom of the pit, the rope will slack and the apparatus will come into action, and press upon the guides.

Broadbent's safety cage, Fig. 720. A are the guides; B the suspending chains; C levers to which the suspending chains are attached, and which, when the weight is carried, keep the eccentrics E from coming in contact with the guides; there is a spring for giving motion to the levers C and eccentrics E when the rope breaks; F a wrought-iron plate at side of cage to carry the apparatus; and G the framework of the cage. When the suspending rope breaks, the springs will force the eccentrics E against the guides, and the cage will remain suspended. Every time the cage is on the keeps, both at the top and bottom of the pit, the rope will slack, and the apparatus will come into action and press upon the guides.

720.



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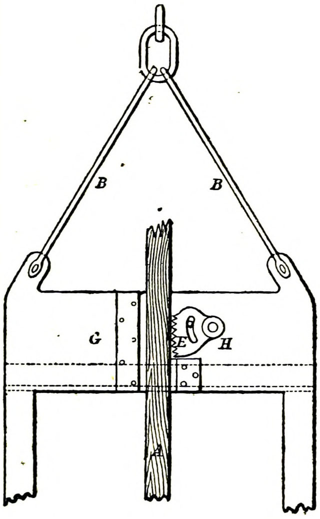

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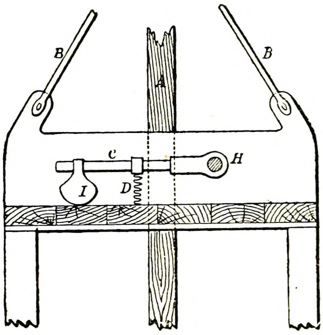

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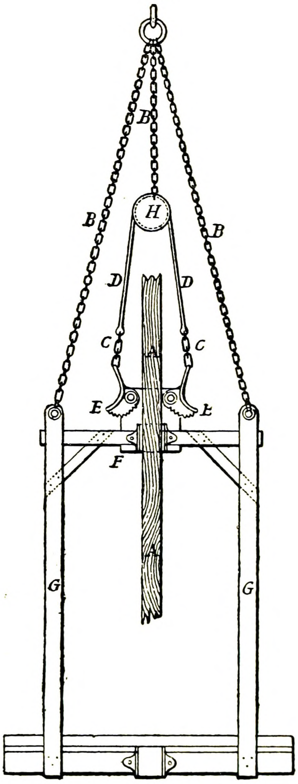
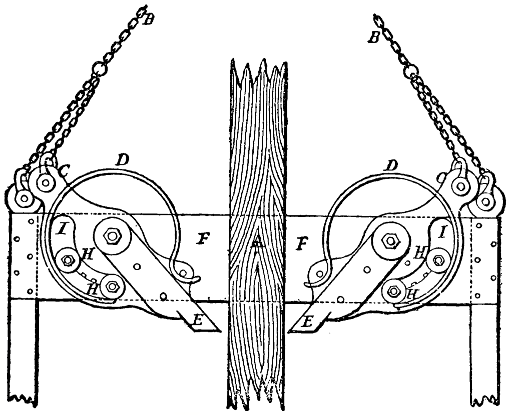


Calow's safety cage, Figs. 721, 722, differs somewhat from those just described, in that it is not dependent for its action on any direct attachment to the rope. A the guides; B the suspending rods or chains; E an eccentric carried by a shaft H, on which is also keyed the lever C; D is a spring which is made to suspend the weight I, and keep the eccentrics clear of the guides, so long as the speed of the descending cage does not approach that of a falling body. But by the cage falling, or through any sudden jerk, the pressure of the weight I on the spring D ceases to be so intense, and therefore the spring lifts it, and sets in motion the eccentric E, which grips the guides and prevents the cage falling. This apparatus therefore does not come into action each time the cage is stopped or resting on the keeps.

A side elevation of King's safety cage is shown in Fig. 723. A is one of the guides; B B are the suspending chains; C C levers to which the suspending chains are attached, and which, when the weight is carried, keep the levers or eccentrics E from coming in contact with the guides; D is a spring on each side of the cage; it is made of a steel bar turned round at H, where it is carried by the suspending chains, and the lower ends are joined on the levers C; thus the spring, when the suspending chains are taut, keeps the eccentrics E away from the guides, but when the suspending apparatus gives way, it forces the levers C outwards, causing the eccentrics E to seize the guides; F is a wrought-iron plate fixed to the side of the cage to carry the apparatus; and G is the framework of the cage. Every time the cage is on the keeps, both at the top and bottom of the pit, the rope will slack and the apparatus will come into operation and press upon the guides. By altering the edges of the levers they can be made to suit iron-wire guides.

Fig. 724 is of Denton and Whittaker's safety cage. A are the guides; B the suspending chains; C levers to which the suspending chains are attached, and which, when the weight is carried, keep the levers E from coming in contact with the guides; D are springs giving motion to the levers C and E when the rope breaks; F is a wrought-iron plate at the side of the cage to carry the apparatus; G the framework of the cage; the springs D are bolted together with a stop H into the plate F, and the levers C are so arranged that the stop works in slots I, which regulate the travel of the levers. When the suspending rope breaks, the springs force the eccentrics E against the guides, and the cage will remain suspended. The apparatus will also come into operation every time the cage is on the keeps, either at the top or bottom of the pit.

724.



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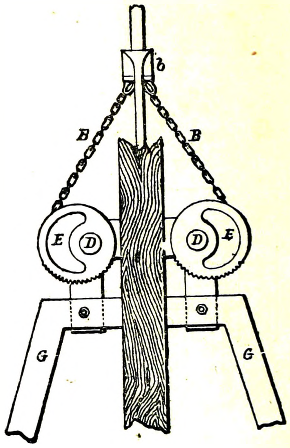
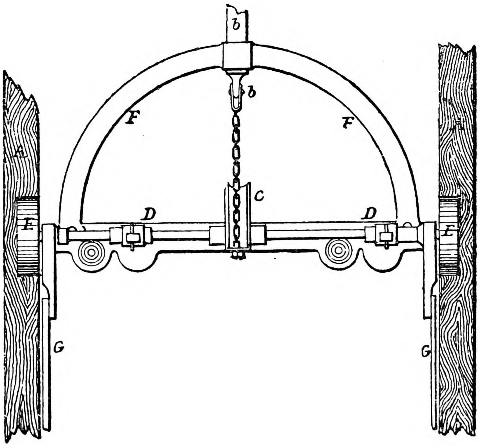


The following is a description of White and Grant's safety cage. Fig. 725 is a side elevation, and Fig. 726 an end view. A are the guides; B suspending chains, which are carried to a bar *b*, which passes through a guide in a bow of F, which is made strong enough to take the whole weight of the cage and is carried by the stop *b'* at the end of *b*; D shafts to which are fixed the quadrants C, and the eccentrics E; and G is the framework of the cage. The action of this apparatus is similar to that of King's safety cage.

726.



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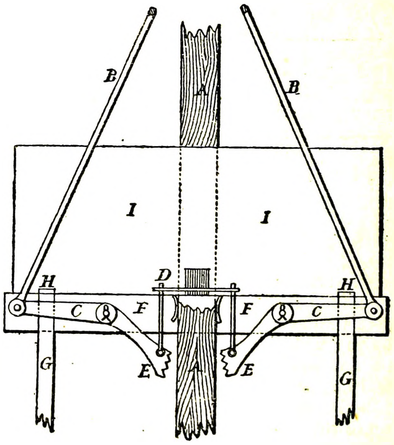
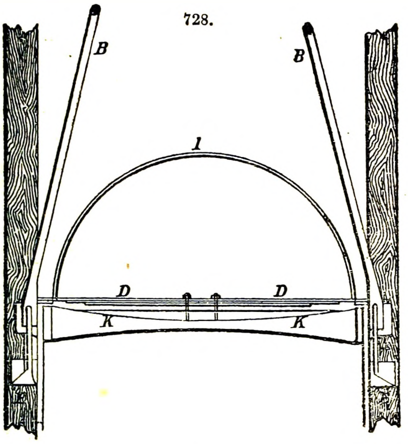
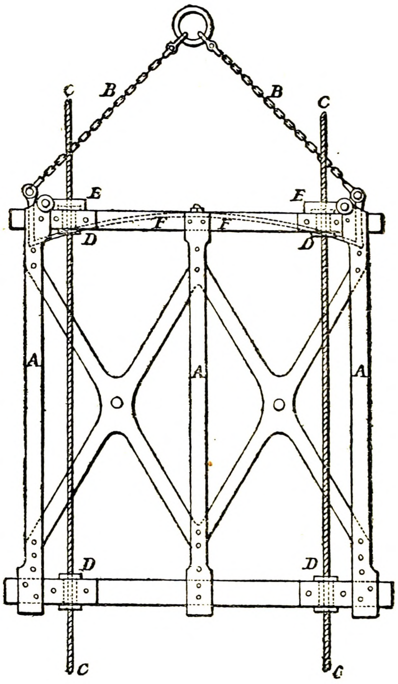


In Whitelaw's safety cage, Figs 727, 728, A are the guides; B the suspending rods; C levers to which the suspending rods are attached; these levers press against the stops H and carry the cage, keeping the levers E from contact with the guides; D is a powerful spring for giving motion to the levers E when the rope breaks; F is a wrought-iron plate at the side of the cage to carry the apparatus; G the framework of the cage; I is a shield, and K a strong bar for securing the spring. When the suspending chain breaks, the springs force the levers E against the guides, and the cage will remain suspended. By the falling of the rods B, the apparatus will come into action every time the cage is on the keeps either at the top or bottom of the pit.

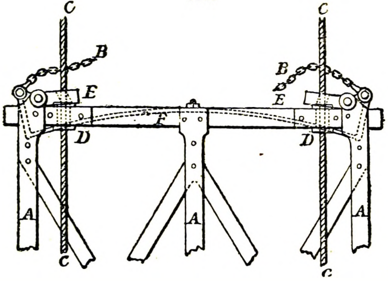
728.



729.



730.



King's safety grip for winding cages, constructed for use with wire-rope conductors, is shown in Figs. 729, 730. Fig. 729 shows the cage attached to the winding rope, and Fig. 730 the grip brought into action by the breaking of the rope. In the figures, A is the framework of the cage; B chains for attaching the cage to the winding rope; C guide-ropes, and D guide-rings attached to the cage, and through which the guide-ropes pass; E the grips; and F a steel spring, which ensures the grips acting immediately the rope is broken. This grip has been largely employed not only in collieries, but also in furnace lifts, and similar appliances.

Safety, or disconnecting hooks, as they are generally called, are intended to prevent the fatal consequences of overwinding. They cause the hook or link by which the cage is suspended from the rope, to release its hold of the rope, by striking against a portion of the framework of the head gear, arranged and placed at a certain height for that purpose; in this way the rope is saved from rupture, while the safety of the cage is left to depend on the ordinary safety apparatus. In some kinds of safety-hook, however, the cage is not only detached from the rope by the action of the hook, but is at the same time suspended by it to the framework of the head gear, and its safety thus depends on the action of one apparatus only.

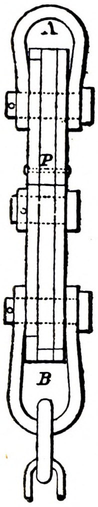
The objection to appliances of this nature lies in their apparent liability to release their hold of the rope, when not required to do so, as the effect of a sudden shock brought upon them. It is, however, but just to remark that hitherto no accident of this kind has occurred.

In the following paragraphs we illustrate and describe the most generally known and adopted of these appliances.

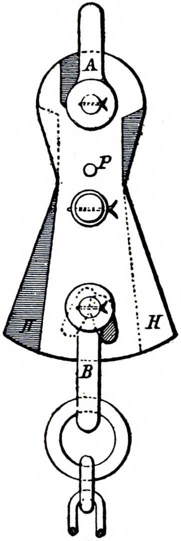
Fig. 731 is an end elevation, and Fig. 732 a side elevation of Ormerod's disconnecting hook. Fig. 733 shows the hook of this apparatus, disconnected from the winding rope, and hanging suspended to the conical cylinder, which is attached to a beam near the top of the pulley frame. The apparatus when attached, as in Fig. 732, is wider at the bottom than at the top. When the hook is drawn into the cylinder E, which is conical, the points H, coming in contact with F, begin to close the bottom, open out the top, and force the shackle A from its seat into the slot D, which allows the rope to go free, at the same time the shackle B is forced out of its seat into the bottom slot D′, and locks itself; and the cage, being suspended from the chain, cannot fall back again. To prevent the link from becoming detached or deranged, at any time, in the pit, it is locked by the pin P.

Calow's disconnecting hook is shown in Fig. 734, attached to the winding rope and to the cage as in work; and Fig. 735 shows the same hook detached. It is made of steel, and held together by means of a slotted plate B. The weight of the cage rests on a pivot D in the centre, which pivot has a constant tendency to divide the upper portion of the hook. The instant the hook comes in contact with the ring A, shown in section, the slotted plate is forced off the lower ends of the two upper plates, cutting the copper rivets, *c c*. The weight of the cage resting upon the pivot opens the jaws and releases itself, and thus prevents overwinding. When at work, as in Fig. 734, the strain is thrown on the slotted plate longitudinally. The slotted plate is shown in plan at B′, Fig. 735, and the bearing for the pivot at D.

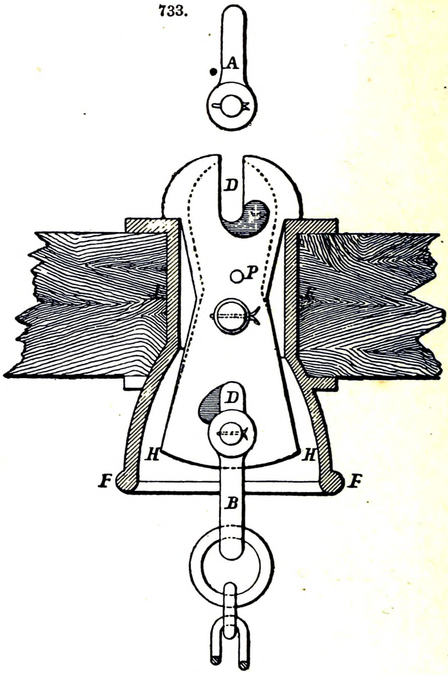
731.



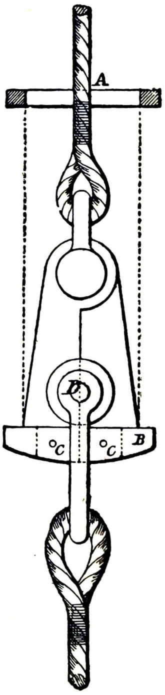
732.



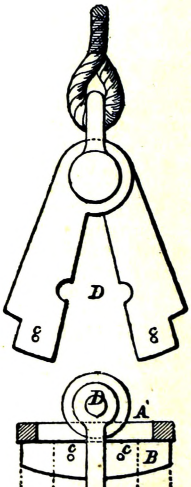
733.



734.



735.

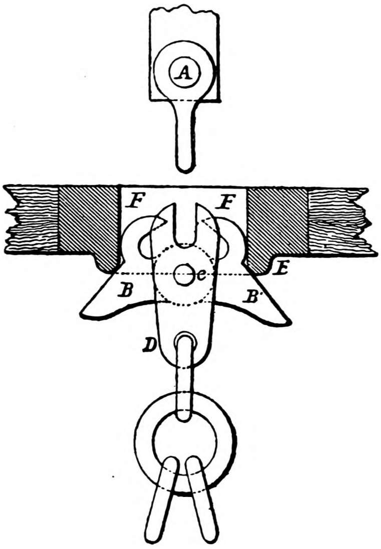


King's disconnecting hook, Figs. 736 and 737, is composed of three pieces, B, B′, and D, joined together by the pin C. B and B′ have hooks at F, which, when in the position Fig. 736, hook over the shackle A, and secure the cage to the rope; but when the projecting ends B B′ press against the ring E, which is suspended near the pulley, they assume the position Fig. 737, and disconnect themselves from the shackle A.

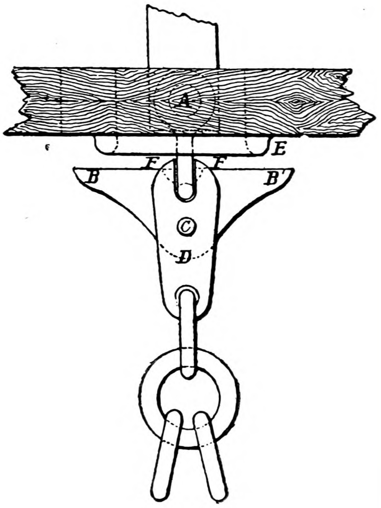
In Denton's disengaging hook, Fig. 738, A acts as an open link, with the bend or hook at *a* very strong, to ensure its bearing the requisite weight; B is a guard, to prevent the ring of the rope slipping off the hook. The guard has open slots, over which two latches *b* drop, to keep the guard in its place, the latches being held down by two springs, one of which is shown at *c*, which bear on studs *b′*. The parts A and B are jointed together at *d*, and the two latches coupled together, by the tail-piece *e* being inserted between them, and all three riveted or bolted together, as at *f*; in the event of the cage being overwound, previous to its going into the pulley, the tail-piece coming in contact with a cross-beam, fixed for the purpose, will, by turning on its joint *g*, lift the latch *b* off the slot, thereby removing the impediment to the separation of A from B at the point *a*, and A having a shoulder at *i*, it follows that when the latch *b* comes in contact with this shoulder and the cage is still going upward, the tail-piece will be arrested by the cross-beam, and turn the portion A of the slip catch over on its back, when the rope-ring K must slip out and leave the catches and cage behind.

Bryham's disconnecting hook is shown in Figs. 739 to 741. Fig. 739 is an end elevation; Fig. 740 a side elevation of the apparatus in working order; and Fig. 741 a side view, showing the cage detached by overwinding. A A are two wrought-iron plates forged with a slot B, to receive the shackle C to which is attached the cage. D is a wrought-iron disengaging plate, forged with the slot E, and fixed between the plates A A, and is kept in its working position by a small brass pin F; G is a wrought-iron plate fixed in the head-gear framing, and having a large hole in it through which the rope works. When the cage is raised too high, the hook, being attached to the rope, is drawn through the plate G; the circular hole in this plate is made of such a diameter as to prevent the hook passing through it without first cutting the small brass pin F, by pressing in the plate D, and removing the shackle C with its load from their working position into the slot B, which is thus disconnected, as in Fig. 741. To prevent the cage from falling down the pit-shaft, catches are fixed in the guides, so arranged that the cage in ascending raises the catches, and immediately it has passed them they fall into their original position, and receive the cage when disconnected from the rope.

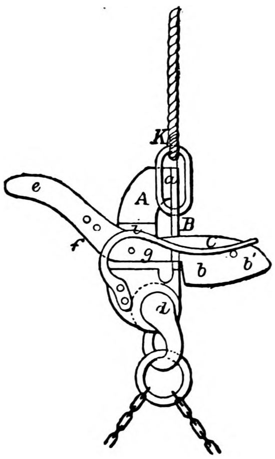
737.



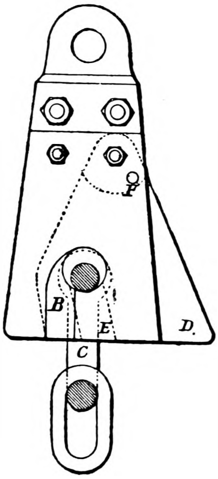
736.



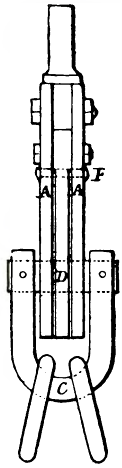
738.



740.



739.

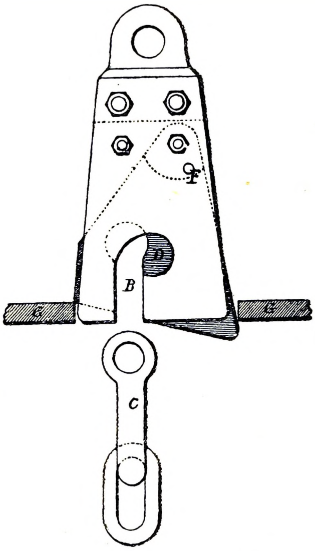


Figs. 742 and 743 are McGill's disconnecting hook. A is the main shank, forged with one portion of the eye, in which the bridle B, with its roller rests. The clip C closes up the eye, and is kept in its place by the spring D, pressing upon a pin at the end of the horns of the clip. The cross-bar E comes in contact with the flanges of the pulley, and causes the eye-bolt to assume a diagonal position, the bridle B and its roller are thus brought on to the clip C, and the weight of the load overcomes the pressure of the spring D, the clip C assumes the position shown in dotted lines in Fig. 742, and the bridle with its load is thus disconnected from the rope. To prevent the cage from falling down the shaft, two catches are fixed in the timber guide-rods, acted upon by springs from behind. When the cage is ascending it forces the catches back, and the moment it is passed they resume their original position, and receive the cage when it is relieved from the rope.

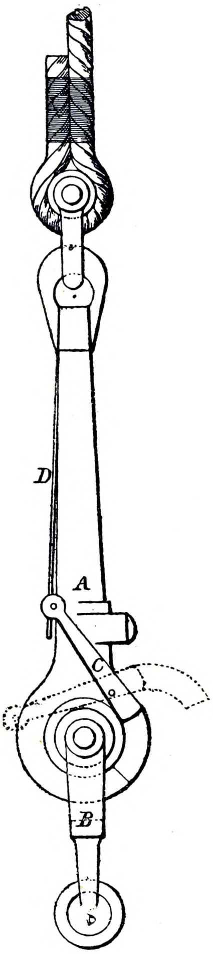
Walker's detaching hook, Figs. 744 to 747, consists of a pair of jaws D, working on a centre pin E, in such a manner that the weight of the load has a tendency to open the upper limbs, which clip the strong centre pin of the shackle A. The upper limbs are formed externally with jaw hooks F; and the jaws kept together, and made to retain the shackle pin by the clamp H, held in position by the pins I. To connect the hook to the winding rope, the pin P of the top shackle A, and fixed on to the eye of the rope by the pin is unscrewed, and the pin passed through the eye of the winding rope; the two are thus connected without the use of an intermediate link.

In case of overwinding, the jaw hooks pass freely into the ring C, but the projections K of the clamp, coming into contact with the bottom flange of the ring, hold the clamp stationary, while the jaws are being pulled through, the result being that the pins I are sheared off, and the jaw hooks released from the restraint of the clamp. The internal diameter of the ring being the same as the width across the jaw hooks F, the rope remains secure until the jaw hooks reach the top of the ring, when, by the action of the weight of the load, they are forced open, and so hook on to the top of the supporting ring C, as in Fig. 747, the rope passing harmlessly over the pulley. It will be observed that the upper edge of the ring C is curved, to match the sweep of the jaw hooks when opening. By this arrangement shock is avoided. The recess O in the ring C is intended to meet an imaginary case, which experiment shows to be almost impossible, namely, that if the engine should be reversed after the pins I are cut, and before the hooks reach the top of the ring, the jaws will then hook into the recess, and the load remain suspended in perfect safety.

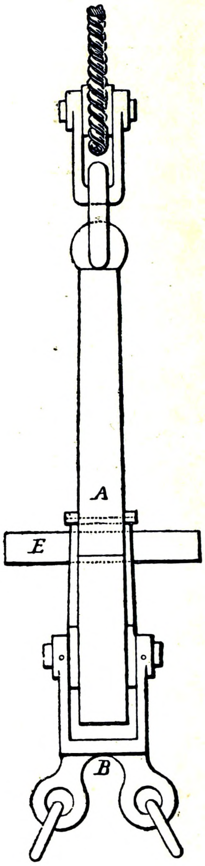
741.



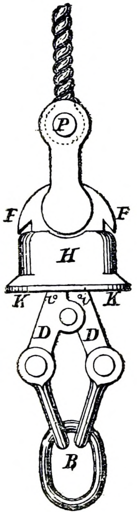
742.



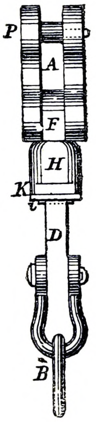
743.



744.

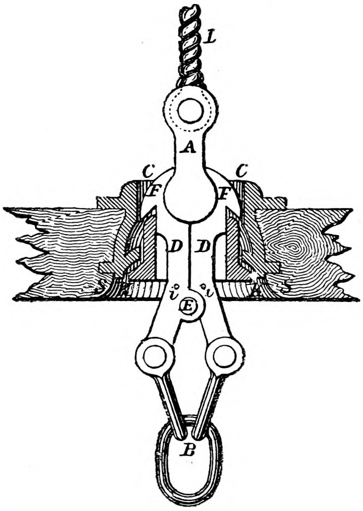


745.

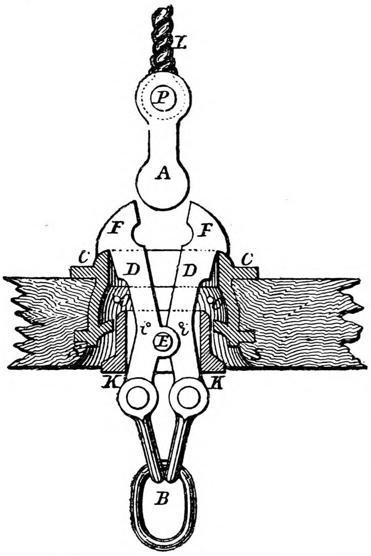


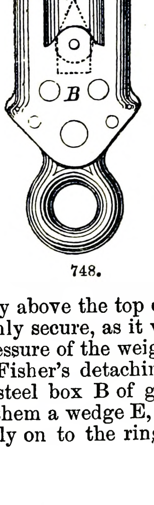
The ring *c* should be firmly fixed in two stout baulks of timber, hollowed out to match the external shape of the ring, as in Figs. 746 and 747, and the timbers firmly bolted together. For an ordinary winding pit, fitted with two cages, both the rings may be put into the same pieces of timber. The strength or depth of wood under the bottom flange will be varied in proportion to the load the rings will have to carry, and care must be taken to have the approaches to the bottom of the rings rounded out sufficiently to clear the projections K of the clamp H, as shown at S, Figs. 746 and 747. To ensure this a rim is left on the under side of the bottom flange; this rim should be left quite clear. The supporting timber should be good sound oak, fixed as near to the pulley as possible. The line of the rope should pass down the centre of the ring, so that the socket of the rope can rise fairly above the top of the ring without being thrown out of line. The timber must be made thoroughly secure, as it will have to resist the upward strain of shearing the pins off, and the downward pressure of the weight of the load.

746.

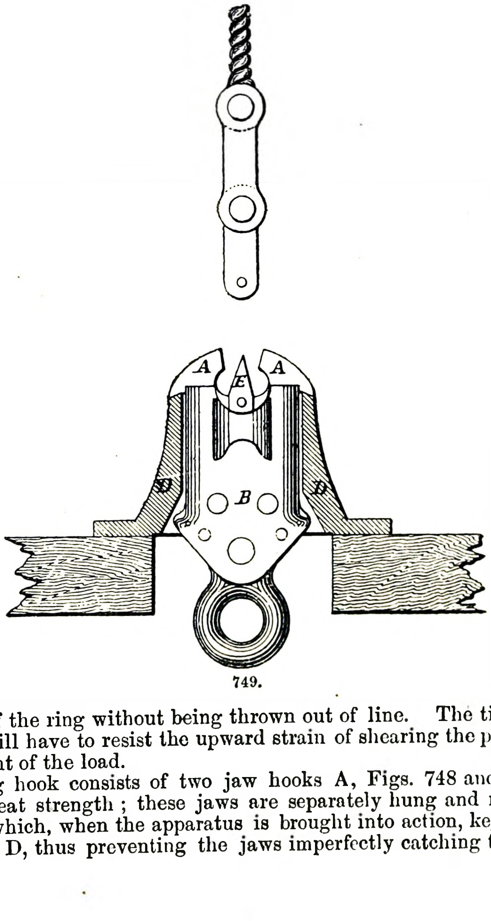


747.





748.

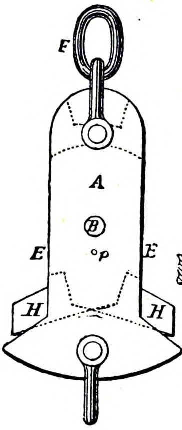


749.

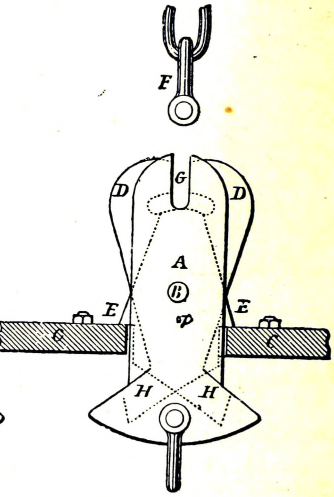
Ramsey and Fisher's detaching hook consists of two jaw hooks A, Figs. 748 and 749, contained in a cast-steel box B of great strength; these jaws are separately hung and moved, and contain between them a wedge E, which, when the apparatus is brought into action, keys the jaws firmly and securely on to the ring D, thus preventing the jaws imperfectly catching the ring, or being shaken off either while the chains are slackened by the momentum of the cage or load, or by its falling back.

King's detaching hook, Humble's arrangement, Figs. 750 and 751, consists of two plates, shown by the dotted lines; these are fixed between a framework of two outer plates A, so as to oscillate about a strong pin B, which passes completely through both the plates and the framework; all of these four plates being for the greater part of their length of the same width. When in operation holding the cage the grip is very firm. C, Fig. 751, represents a section through the ring or catch plate for disconnecting and suspending the hook. This plate should be firmly bolted on to the top side of oak beams, set at a proper distance apart, and securely fastened to the head gear. The dimensions of these beams should be such as to allow of a wide margin of safety, over the load which they will have to carry, as before remarked.

750.



751.



In case of overwinding, the whole of the apparatus is drawn upwards until the projections H come in contact with the guide plate C, which presses them inwards, thus shearing the locking pin P, and forcing out the points E, at the same time allowing the top shackle F to escape by the slot G. The projections E then drop back upon the guide plate C, and the cage is thus suspended, and, together with its contents, preserved from injury.

In order to prevent the possibility of overwinding the cage without using safety hooks, winding engines are often fitted with a powerful self-acting steam brake, which is brought into action as soon as the cage emerges from the shaft.

In an apparatus of this kind used at Clay Cross, Derbyshire, the ascent of the cage shuts off the steam, and puts in motion an ordinary brake, which stops the engine before the cage gets 3 ft. above the landing. Another plan is to use a pair of coupled horizontal engines, the steam being gradually shut off as the cage approaches the surface, by the automatic reversing of the working lever; and the steam brake, if the cage ascends too far, is thrown on before the cage can reach the pulley.

CALCULUS.

The term calculus, although generic, is usually applied to the mathematical methods more definitely known as the Differential and the Integral Calculus. It would be impossible to include in any one work a complete list of reduction formulæ, applicable to all cases requiring this class of investigation, and the information in these pages has been confined to the description of the elements of the calculus, so far as are likely to be of use to the practical engineer. Those who wish to pursue the subject in its more abstract relations are referred to the various text-books.

Before describing the object of the calculus, it is necessary to point out the nature of the ideas on which it is based. The differential calculus deals with infinitely small quantities, or quantities which may be made as small as we please, and we may at any time take these quantities to be so small that, when necessary, they may be disregarded. Between any two or more limits an infinite number of terms may exist, constantly approximating to a subsequent term, which is one of the limits, but which is never reached. This idea is difficult to grasp, but that it is feasible is illustrated by the following numerical example. Let there be constantly added to one term, say 1, any number of terms, in such a manner that the term added is half that which precedes; the series will go on gradually approximating in its sum to the other limit, say 2, but never attaining this other limit. Thus

$$1 + \tfrac{1}{2} + \tfrac{1}{4} + \tfrac{1}{8} + \tfrac{1}{16} + \tfrac{1}{32} + \ldots.$$

never is equal to 2, although it may be brought as near to equality as we like, by continuing the series to a sufficient length.

A quantity also may be of appreciable dimensions in itself, but compared with another quantity becomes quite unworthy of appreciation, examples of which are occurring in everyday practice. Thus, the expansion by heat of an iron bar or girder may be inappreciable, except in only one dimension, that of its length; and in calculating for the effects of temperature we may neglect any expansion except in this direction. The doctrine of infinitesimal quantities, when regarded from a practical and not from a metaphysical point of view, is thus not difficult to grasp, and enables us to understand more easily than any other basis the applications of the calculus.

The object of the differential calculus is, to determine how small changes in some variable quantity, cause variations in the value of a quantity depending upon this variable quantity. In some branches of physics, by considering the variations experienced by a single molecule, the total effect on the whole body may be learnt.

The integral calculus has for its aim to ascertain from the ratio of such changes, the governing function or law of these changes. Its object is therefore just the reverse of that of the differential calculus.

Both the calculi differ in their operations from those of ordinary algebra, by dealing with variable instead of constant quantities. It is usual with mathematicians, when dealing with constant quantities which retain the same value throughout the problem, to represent these quantities by the earlier letters of the alphabet, $a, b, c, \ldots$ and variable quantities by the later letters, as x, y, z.

The dependence of a quantity y upon another quantity x is expressed by a formula, as $y = a\,x^m$, and y is said to be a function of x, and the equation may be written under a general form $y = f\,(x)$ which does not tell us anything of the exact relation until the definite or determinate form is known. As an unlimited number of solutions may be found for $y = f\,(x)$, that one of the variables, x, which may be chosen at will is termed the independent variable, and y the dependent variable. In $y = a\,x^m$, a and m are constant, because if these were to vary, no one definite law could ever be determined from the relation of y to x. There may be, however, two or more variables, as $z = f\,(x, y)$, and the case meet with solution if there are a sufficient number of equational relations given to determine the law.

All such relations admit of graphical illustration, thus the area of a parallelogram depends upon its breadth and length, the contents of a solid upon an additional variable of width.

If the independent variable of a function, such as the abscissa A M $= x$, Fig. 752, is increased by an infinitely small quantity M N $= d\,x$, termed the differential of x, the ordinate or dependent variable $y =$ M P becomes N Q, and is increased by a corresponding differential $d\,y$.

The two letters, $d\,x$, $d\,y$, represent one quantity in each case, and it is not to be understood that d is to be multiplied into y or x as in ordinary algebra. Upon this reasoning

$$y + d\,y = f\,(x + d\,x),$$

and

$$d\,y = f\,(x + d\,x) - f\,x,$$

by ordinary algebra, and is the general rule for the determination of the differential of a function.

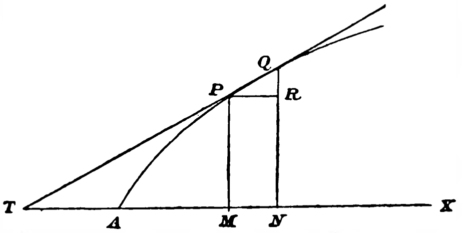
If $y = x^2$, $d\,y = (x + d\,x)^2 - x^2 = (x^2 + 2\,x\,d\,x + d\,x^2) - x^2 = 2\,x\,d\,x + d\,x^2$. As $d\,x$ is small or fractional its square will be smaller, and may be disregarded, so that $d\,y = 2\,x\,d\,x$, and $\frac{d\,y}{d\,x} = 2\,x$, the ratio of the differentials.

The general rule for differentiation is sometimes expressed thus; To differentiate any power of the variable x, deduct one from the index of the variable, and multiply by the original index, thus $d\,(x^n) = n\,x^{n-1}$. The following table includes some general examples of differentiation, it being understood that constant multipliers or divisors of a variable quantity remain unchanged by differentiation, but that terms added or subtracted disappear. Thus $d\,(n\,x^3) = 3\,n\,x^2\,.\,d\,x$; and $d\,(n + x^3) = 3\,x^2\,.\,d\,x$.

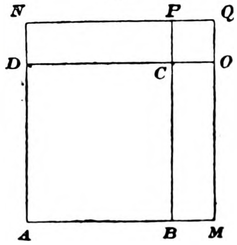
TABLE OF DIFFERENTIAL COEFFICIENTS.

$y =$	$\frac{d\,y}{d\,x} =$	$y =$	$\frac{d\,y}{d\,x} =$
x^n	$n\,x^{n-1}$	$\sin.\,x$	$\cos.\,x$
$-\,x^{-\frac{1}{2}}$	$\frac{1}{2}\,x^{-\frac{3}{2}}.$	$\cos.\,x$	$-\sin.\,x$
$\frac{1}{x^{\frac{2}{3}}} = x^{-\frac{2}{3}}$	$-\frac{2}{3}\,x^{-\frac{5}{3}}$	$\tan.\,x$	$\frac{1}{\cos.^2 x}$
$a\,x^2 + b\,x + c$	$2\,x + b$	$\cot.\,x$	$-\frac{1}{\sin.^2 x}$
$\log._{\epsilon}\,x$	$\frac{1}{x}$	$\sec.\,x$	$\frac{\sin\,x}{\cos.^2 x}$
a^x	$a^x \log._{\epsilon}\,a$	$\operatorname{cosec}.\,x$	$-\frac{\cos.\,x}{\sin.^2 x}$

752.



753.



The contents of a square are represented by $y = x^2$, or A B C D, Fig. 753, and by the addition of the differential B M $= d\,x$, the square is enlarged by two spaces B O and D P $= 2\,x\,d\,x$, and by a square, $d\,x^2$, which latter we may neglect as we are to consider B M very small, so that by the addition of $d\,x$, the square or y is increased by $2\,(x\,d\,x)$, x being the side A B. This graphically illustrates the simplest example of differentiation.

The tangent to the curve T P Q, Fig. 752, is determined in direction by the angle P T M $= a$, and when the curve is concave this line is outside, but if it were convex, the tangent would be inside between the curve and the abscissa-axis. Supposing P Q R to be an infinitely small right-angled triangle with the base P R $= dx$, and R Q $= dy$, the angle Q P R = P T M $= a$, and tan. Q P R $= \frac{\text{QR}}{\text{PR}}$, or tan. $a = \frac{dy}{dx}$; so that the ratio of the differentials dy and dx gives the *trigonometrical* tangent of the tangential angle a. The portion of the tangent P T, Fig. 752, is generally termed the tangent, and its projection upon the abscissa-axis, or T M, the sub-tangent. Therefore, subtan. = P M cot. P T M $= y$ cot. $a = y \frac{dx}{dy}$.

That the constant members of a function disappear by differentiation, is better understood from consideration of the following example. In the curve A P Q, Fig. 754, P R $= dx$ and R Q $= dy$; and in the curves A P_1 Q_1 and A P Q, Fig. 755, also the corresponding ordinates have definite relation to one another, and the relation between the differentials $\text{R}_1 \text{Q}_1 = \text{N}_1\text{Q}_1 - \text{M P}_1$ and $\text{R Q} = \text{N Q} - \text{M P}$ is the same, and will continue so, however many times the diagram may be enlarged or diminished with preservation of existing proportions.

If $y = u + v$, or the sum of two variables, $dy = u + du + v + dv - (u + v)$, or $d(u + v) = du + dv$. That is, the differential of the sum of several functions is equal to the sum of the differentials of the separate functions. This is shown, Fig. 755, by consideration of the curve A P Q. If M P $= f(x)$ and $\text{P P}_1 =$ another function of x or $f^1(x)$,

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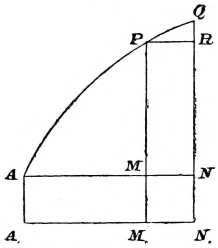

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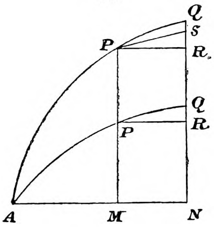

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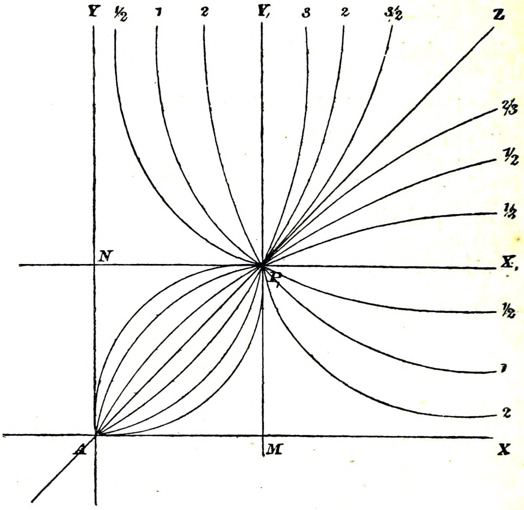


$\text{M P}_1 = y = f(x) + f^1(x)$ and $dy = \text{R}_1 \text{Q}_1 = \text{R}_1 \text{S} + \text{S Q}_1 = \text{R Q} + \text{S Q}_1 = df(x) + df^1(x)$; because P_1 S can be drawn parallel to P Q_1 and consequently R_1 S put = R Q and Q S = P P_1.

If u and v are the unequal sides of a rectangle, $y = uv$ will represent the area, and $dy = (u + du)(v + dv) - uv = uv + udv + vdu + + dudv - uv = udv + vdu + dudv = udv + (v + dv)du$. And as dv compared to v is indefinitely small, we can put $v + dv = v$ and $(v + dv)du = vdu$; also $udv + (v + dv)du = udv + vdu = d(uv)$. The differential of the products of two variables is equal to the sum of the products of each variable by the differential of the other.

Similarly it may be found for the differential of a quotient $y = \frac{u}{v}$, by putting $u = vy$, that

$$du = vdy + ydv, \text{ and } dy = \frac{du - ydv}{v} = \frac{du - \frac{n}{v}dv,}{v} \text{ or } d\frac{u}{v} = d\,\frac{vdu - udv}{v^2}.$$

If on the coordinate axes, Fig. 756, from the point A, at the distances $x = \pm 1$ and $y = \pm 1$ we draw the parallels N X_1 M Y_1 and the diagonal Z through the point P_1, we shall be able by repeating this diagram on the three remaining quadrantal arcs around A, to obtain all the curves given by the equation $y = x^n$. For every point on the abscissa-axis, $y = 0$, and for every point on the ordinate axis, $x = 0$; for points in N X_1, $y = \pm 1$, the sign changing according to the position of the quadrant, and in M Y_1, $x = \pm 1$.

If $x = 1$, $y = 1$ or -1, consequently all these curves pass through a point P_1 whose ordinates are A M = 1 and A N = 1. If $n = 1$, we have all points in the line A Z. If n is greater than 1, convex curves are obtained, and if n is less than 1, the curves will be concave. If n is taken as variable and is gradually decreased until it = 0, the ordinates approach the value $y = x^0 = 1$, and the curve approaches the abrupt line A N P_1 X_1; but if n is increased, y approaches $x\infty = x^{\frac{1}{0}} = \infty$, and $x = y^0 = 1$, the curve approaching A M P_1 Y_1. If $n = -1$, $y = x^{-1}$, and the curve approaches the axes but never reaches them, and its curvature is convex or concave as n is smaller or greater than unity. If n is an entire odd number, y and x have the same sign; if even, y becomes positive for all values of x.

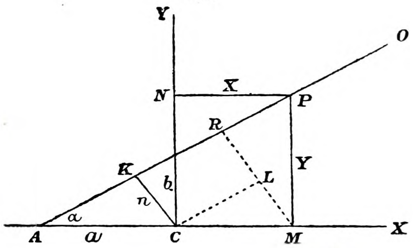
If in $y = x^{\pm \frac{1}{n}}$, n is an entire odd number, y and x have the same signs, and if n is an entire even number, every positive value of x has two equal values for y, one of which is positive and the other negative, and every negative value of x has y imaginary or impossible. Corresponding curves are found only in the first and third quadrants in the first case, and in the first and second quadrants in the second case, approaching as $m = \infty$, the values X_1 N A and X_1 N Y.

These curves enable us to determine from inspection of any formula involving $y = x^n$, the course of the curve in the special instance.

From the formula $d(x^n) = n\,x^{n-1}\,dx$, the formula for the tangential angle represented by these curves is tan. $a = \frac{dy}{dx} = n^{x-1}$, and the subtangent $= y\frac{dx}{dy} = \frac{x^n}{n\,x^{n-1}} = \frac{x}{n}$.

When a straight line A O, Fig. 757, cuts the abscissa-axis at an angle O A X, represented by a, and lies at a distance C K, represented by n from the coordinate origin C, the equation of a point in this line is y cos. $a - x$ sin. $a = n$, and because $n =$ M R $-$ M L, M R $= y$ cos. a and M L $= x$ sin. a. When $x = 0$, $y =$ C B $= b = \frac{n}{\text{cos.}\,a}$ and $n = b$ cos. a, and y cos. $a - x$ sin. $a = b$ cos. a, or $y = b + x$ tan. a. The lines C A and C B measuring the distances from where the line cuts the axes to their origin, are termed the parameters of the line, and are usually designated by the letters a and b. As C A $= -a$, tan. $a = \frac{\text{C B}}{\text{C A}} = -\frac{b}{a}$, and the equation of the straight line becomes $y = b - \frac{b}{a}\,x$, or, $\frac{x}{a} + \frac{y}{b} = 1$.

757.



A line, which lies at a determinate distance from the origin of coordinates, and to which a curve gradually approaches without ever entering into actual coincidence, is termed the asymptote of the curve. Some mathematicians consider the asymptote as the tangent to a point of the curve situated at an infinite distance, and under this form the equation admits of easy treatment by the calculus. The angle that the tangent makes with the abscissa-axis can be learnt from the relation tan. $a = \frac{dy}{dx}$ and the distance n from $n = y$ cos. $a\,x -$ sin. $a = (y - x$ tan. $a)$ cos. $a = \frac{y - x\,\text{tan.}\,a}{\sqrt{1+(\text{tan.}a)^2}} = \frac{y - x\frac{dy}{dx}}{\sqrt{1+\left(\frac{dy}{dx}\right)^2}}$, when the value of x is substituted and y put $= \infty$. In order that the converse may hold good, or that a tangent to an infinitely distant point may be an asymptote, when x or $y = \infty$, $y =$ tan. a, or y cos. $a - x$ must not become infinitely great. In the curves, Fig. 756, the abscissa-axis represents the conditions of tan. $a = \infty$ and $n = 0$, and the ordinate axis, tan. $a = 0$ and $n = 0$; and these axes are therefore asymptotes to the curve of the equation $y = x^{-n}$.

The greatest value of the calculus to the engineer consists in the aid it affords, in the determination of cases of maxima and minima, as well as in learning at what point changes of condition occur. After stating the principle, a few examples will illustrate the subject sufficiently to place in the hands of any ordinary algebraist a tool, the value of which he can at once ascertain for himself.

If successive values of x be substituted in the ratio of the differentials $\frac{dy}{dx}$ which, it has been seen, is the formula for the tangent of the tangential angle, all the positions of the tangent to the corresponding curve are obtained. When $x = 0$, the tangent of the angle at the origin of the coordinates is obtained, and when $x = \infty$ the tangent of the angle for an infinitely distant point. By determining where the tangent to the curve runs parallel to either of the coordinate axes, because then one or other of the coordinates x or y have their greatest or least value, the maximum or minimum value of x or y is obtained. When the curve is parallel to the abscissa-axis, $a = 0$, and tan. $a = 0$; when parallel to the ordinate axis, $a = 90°$ or tan. $a = \infty$. Hence the following rule;—

To find the value of x corresponding to the maximum or minimum of y, put the ratio of the differentials $\frac{dy}{dx} = 0$, or $= \infty$, and resolve the resulting equation with regard to x.

The equation of the curve, Fig. 758, is $y = 6x - 4\frac{1}{2}.x^2 + x^3$, and

$$\frac{dy}{dx} = 6 - 9x + 3x^2 = 3(2 - 3x + x^2) = 3(1 - x)(2 - x).$$

Putting $\frac{dy}{dx} = 0$, $1 - x = 0$, and $2 - x = 0$, or $x = 1$ and $x = 2$. Substituting these values in the foregoing formula for y, the maximum value of y or M P is $= 6 - 4\frac{1}{2} + 1 = 2\frac{1}{2}$, and the minimum value N Q $= 12 - 18 + 8 = 2$.

When a curve is convex to the abscissa-axis, the differential of the tangential angle is positive; when concave, the differential is negative, and when the differential of tangential angle $= 0$, there is a change of curvature in the curve, and the ordinate at this point is neither at a maximum nor at a minimum.

This refers to the differential of tan. a, and as $\frac{d\,y}{d\,x}$ = tan. a, the expression becomes d (tan. a) or $d\left(\frac{d\,y}{d\,x}\right)$, or to the differential of a differential ratio, termed by mathematicians the second differential. The obtaining of differentials of higher order than the first, or successive differentiation, as it is termed, will be presently explained.

Fig. 759 illustrates a curve with a point of inflexion or change of curvature, and Fig. 760 a curve of converse character.

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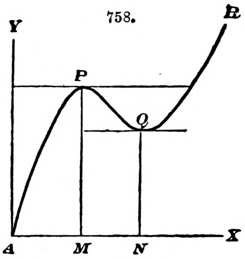

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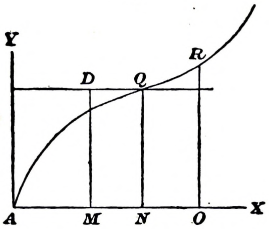

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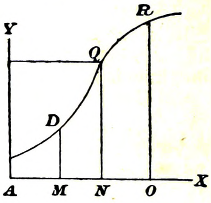


As an example of the application of the calculus to the determination of the conditions of obtaining a maximum, let it be required to learn the dimensions of a cylinder, which for a given contents V has the smallest surface S. Denoting the diameter of the base of the cylinder by x and the height by y, the contents $V = \frac{\pi}{4} x^2 y$. The surface or the area of the ends added to that of the cylindrical surface,

$$S = \frac{2\,\pi\,x^2}{4} + \pi\,x\,y.$$

The first equation $V = \frac{\pi}{4}\,x^2\,y$ gives

$$\pi\,y = \frac{4\,V}{x^2} \text{ or } \pi\,x\,y = 4\,V\,x^{-1}.$$

Substituting this value of $\pi\,x\,y$,

$$S = \frac{\pi\,x^2}{2} + 4\,V\,x^{-1}.$$

S and x may be treated as coordinates of a point in a curve, and then

$$\tan.\ a = \frac{d\,S}{d\,x} = \pi\,x - 4\,V\,x^{-2}.$$

Equating this to 0,

$$\pi\,x = \frac{4\,V}{x^2} \text{ or } \pi\,x^3 = 4\,V.$$

This equation carried out with regard to x, gives $x = \sqrt[3]{\frac{4\,V}{\pi}}$, and the second differential or $d\left(\frac{d\,S}{d\,x}\right) = \left(\pi + \frac{8\,V}{x^3}\right) d\,x$, being positive, this value satisfies the minimum conditions, or the height must be made equal to the width.

As another illustration, let it be required to learn the dimensions of a cylindrical vessel which for a given contents will need the smallest amount of material. From the preceding,

$$S = \frac{\pi\,x^2}{4} + 4\,V\,x^{-1},$$

and from this

$$\frac{\pi\,x}{2} = \frac{4\,V}{x^2},$$

whence

$$x = 2\sqrt[3]{\frac{V}{\pi}} \text{ and } y = \tfrac{1}{2}\,x,$$

or the height must be only one-half the width.

As a practical example, let it be required to find when the strain is at a maximum in a lattice girder. Let W be the weight distributed; S the strain at centre of top and bottom flanges; L the length of bearing of girder, or otherwise the span; D the effective depth of girder; and x the distance of any point from the abutment. The formula given for S is

$$\frac{W}{2\,D\,L}\,(L\,x - x^2).$$

$\frac{W}{D\,L}$ is a constant multiplier in all cases, and we may substitute for it the letter a.

$$\text{Then } S = a\,(L\,x - x^2).$$

Differentiating,

$$\frac{d\,\mathrm{S}}{d\,x} = a\,\mathrm{L}\,x^{1-1} - 2\,a\,x^{2-1} = a\,\mathrm{L} - 2\,a\,x.$$

Putting this $= 0$, $2\,a\,x = a\,\mathrm{L}$, or $2\,x = \mathrm{L}$, or $x = \frac{\mathrm{L}}{2}$ or at half the span. Since the second differential, or differential of $a\,\mathrm{L} - 2\,a\,x$ is $-\,2\,x$, or is negative, S is in this case at a maximum.

Again, in any girder, whether straight, curved, continuous, or not, if the bending moment at any point be expressed as a function of the variable x, the shearing force at the same point is expressed by the differential coefficient (ratio) of this function.

Thus, the bending moment being expressed by $\mathrm{B} = \mathrm{W}\ (2\,a\,x - x^2)$, the shearing force will be

$$\frac{d\,\mathrm{B}}{d\,x} = \mathrm{W}\ (2\,a - 2\,x) = 2\,\mathrm{W}\ (a - x).$$

Successive Differentiation.—By differentiating a first differential d, a second differential is obtained. Thus, representing the first coefficient by $\frac{d\,y}{d\,x}$, the second becomes $\dfrac{d\left(\frac{d\,y}{d\,x}\right)}{d\,x}$ or $\frac{d^2\,y}{d\,x^2}$, and as a third result there is obtained $\dfrac{d\left(\frac{d^2\,y}{d\,x^2}\right)}{d\,x}$ or $\frac{d^3\,y}{d\,x^3}$. In these examples, $d^2\,y$, $d^3\,y$, the indices are only symbols of the successive differentiation as regards the numerators, but in the denominators the index denotes the actual power of x.

$$\mathrm{I}\ \frac{d\,y}{d\,x} = 3\,a\,x^2, \frac{d^2\,y}{d\,x^2} = 6\,a\,x.$$

And if $y = a^x$,

then $\frac{d\,y}{d\,x} = \log._\epsilon\,a\,.\,a^x$; $\frac{d^2\,y}{d\,x^2} = (\log._\epsilon\,a)^2\,a^x$; $\frac{d^3\,y}{d\,x^3} = (\log._\epsilon\,a)^3\,a^x$; $\frac{d^4\,y}{d\,x^4} = (\log._\epsilon\,a)^4\,a^x$, etc.

If $y = \log._\epsilon\,x$,

then $\frac{d\,y}{d\,x} = \frac{1}{x}$; $\frac{d^2\,y}{d\,x^2} = -\,\frac{1}{x^2}$; $\frac{d^3\,y}{d\,x^3} = +\,\frac{1\,.\,3}{x^3}$; $\frac{d^4\,y}{d\,x^4} = -\,\frac{1\,.\,2\,.\,3}{x^4}$; $\frac{d^5\,y}{d\,x^5} = +\,\frac{1\,.\,2\,.\,3\,.\,4}{x^5}$, etc.

If $y = \sin.\,x$,

then $\frac{d\,y}{d\,x} = +\cos.\,x$; $\frac{d^2\,y}{d\,x} = -\sin.\,x$; $\frac{d^3\,y}{d\,x^3} = -\cos.\,x$; $\frac{d^4\,y}{d\,x^4} = +\sin.\,x$; $\frac{d^5\,y}{d\,x^5} = +\cos.\,x$, etc.

If m be the number of times of successive differentiation, the following table will give the series that may be developed ;—

If $y =$	$\frac{d^m\,y}{d\,x^m} =$
x^n	$n\,(n-1)\,.\,.\,.\,.\,[n-(m-1)]\,x^{n-m}$
x^{-n}	$(-1)^m\,n\,(n+1)\,.\,.\,.\,.\,n+(m-1)\,x^{-(n+m)}$
x^x	$(\log._\epsilon\,a)^m\,a\,x$
$\sin.\,n^x$	$n^m\sin.\,(n\,x + \frac{1}{2}\,m\,\pi)$
$\log.\,x$	$(-)^{m-1}\,(m-1)\,(m-2)\,.\,.\,.\,.\,3\,.\,2\,.\,1\,x^{-m}$
$\frac{1+x}{1-x}$	$2\,(1-x)^{-m+1}\,m\,(m-1)\,(m-2)\,.\,.\,.\,.\,3\,.\,2\,.\,1$

If y be a function of x which it is possible to develop into a series of ascending powers of x, and let h be any indeterminate quantity, then $y = \mathrm{A} + \mathrm{B}\,x + \mathrm{C}\,x^2 + \mathrm{D}\,x^3 + \mathrm{E}\,x^4$, etc. When x becomes by a small increment $x + h$, y becomes y^1 and

$$y^1 = y + \frac{d\,y}{d\,x}\,h + \frac{d^2\,y}{d\,x^2}\cdot\frac{h^2}{1\,.\,2} + \frac{d^3\,y}{d\,x^3}\cdot\frac{h^3}{1\,.\,2\,.\,3} + \frac{d^4\,y}{d\,x^4}\cdot\frac{h^4}{1\,.\,2\,.\,3\,.\,4} + \text{etc.},$$

which is Taylor's theorem ; or

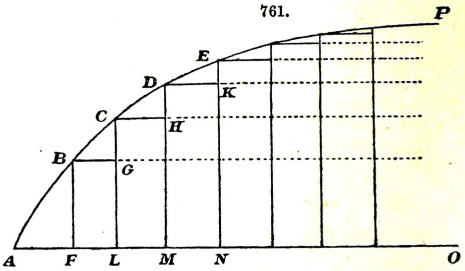
$$y^1 = y + \frac{d\,y}{d\,x}\,x + \frac{1}{1\,.\,2}\left(\frac{d^2\,y}{d\,x^2}\right)\cdot x^2 + \frac{1}{1\,.\,2\,.\,3}\cdot\left(\frac{d^3\,y}{d\,x^3}\right)x^3 + \text{etc.},$$

which is Maclaurin's theorem.

The value of the differential calculus, in this branch of mathematics, is not so apparent to the practical man, but to the algebraist the saving of labour will be at once evident.

Integration.—The ordinates, Fig. 761, may be considered as consisting of an indefinite or infinite number of elements, not necessarily equal, because of their smallness, F B, G C, H D, K E, corresponding to the equal differentials $d\,x = \mathrm{A\,F} = \mathrm{F\,L}$, etc., and when $d\,y = f(x)\,d\,x$, y can be determined by summing all the values of $d\,y$, obtained by substituting successively in $f(x)$, $d\,x$ for x, $d\,x$, $2\,d\,x$, &c., to $n\,d\,x = x$. This summation is the process of integration, and is designated by the sign $\int$, summa, placed before the general expression of the differential the sum of which is to be taken. Thus for $y = [f\,(d\,x) + f\,(2\,d\,x) + f\,(3\,d\,x) + \,.\,.\,.\,.\, f\,(x)\,]\,d\,x$, is written, $y = \int f(x)\,d\,x$; and y is termed the integral. The integral is sometimes to be obtained by summing up the series, but the simpler proceeding is to employ one of the rules of the integral calculus.

761.



Let n be the number of differentials $d\,x$ contained in x, then $x = n\,d\,x$, or $d\,x = \frac{x}{n}$, and

$$\int f\,(x)\,d\,x = \left[f\left(\frac{x}{n}\right) + f\left(\frac{2\,x}{n}\right) + f\left(\frac{3\,x}{n}\right) + \,.\,.\,.\,.\, + f\left(\frac{n\,x}{n}\right)\right]\frac{x}{n}.$$

For the differential $d\,y = a\,x\,d\,x$,

$$y = \int a\,x\,d\,x = a\,d\,x\,(d\,x + 2\,d\,x + 3\,d\,x + \,.\,.\,.\,.\, + n\,d\,x) = (1 + 2 + 3 + \,.\,.\,.\,.\,. + n)\,a\,d\,x^2.$$

When the number of terms n is infinite, the rules of the summation series show that for

$$1 + 2 + 3 + 4 + 5\,.\,.\,.\,. + n = \tfrac{1}{2}n^2 \text{ and } d\,x^2 = \frac{x^2}{n^2},\ y = \int a\,x\,d\,x = \tfrac{1}{2}\,n^2\,a\,\frac{x^2}{n^2} = \frac{a\,x^2}{2}$$

Whence the rule for integration;—Add one to the index of the variable, and divide by the index thus increased. The general formula for the rule is $\int x^n\,d\,x = \frac{x^{n+1}}{n+1}$. Thus $\int 3\,a\,x^2\,d\,x = \frac{3\,a\,x^{2+1}}{3} = a\,x^3$.

A constant factor or divisor may be removed from the process of integration, thus

$$\int b\,d\,x = b \int d\,x.$$

An additive or subtractive term must reappear in integration in the form of an arbitrary constant, thus $\int 3\,x^2\,d\,x = x^3 + c$.

The signs of integration and differentiation neutralize one another, so that $\int d\,x = x$.

These rules are clearly the converse of those given for differentiation.

When the constant c cannot be determined by mere integration, the process gives only an *indefinite* integral; and in order to find the value of the constant, two of the corresponding values of x and $y = \int f\,(x)\,d\,x$ must be found. If for $x = l$, $y = m$, and $y \int f\,(x)\,d\,x = c + f^1\,(x)$, then $m = c + f^1\,(l)$, and $y - m = f^1\,(x) - f^1\,(l)$, and the constant $x = m - f^1\,(l)$.

The determination of the constant leaves the integral still indefinite, for any value of x can be assumed. If the definite value m, of the integral corresponding to the definite value l, of x, is required, this value must be substituted in the integral already found, or $m_1 = m + f^1\,(l_1) - f^1\,(l)$.

Thus, the indefinite integral $y = \int x\,d\,x = \frac{x^2}{2}$ gives for $x = 1$, $y = 3$, the constant $c = 3 - \frac{1}{2} = 2\frac{1}{2}$; therefore the integral $y = \int x\,d\,x = c + \frac{x^2}{2} = \frac{5 + x^2}{2}$; and for $x = 5$, $y = 15$.

But the value of x for which y becomes equal to zero is generally known, and in that case $\mathrm{K} = 0$; so that any indefinite integral of the form $\int f\,(x)\,d\,x = f^1\,(x)$ gives the definite form $m_1 = f^1\,(l_1) - f^1\,(l_1)$. This can also be found by substituting in the expression for the function of x in the indefinite integral the two given limits, l_1 and l of x, and by subtracting the values found from one another. The process is represented symbolically by

$$\int_l^{l_1} f(x)\,d\,x, \text{ so that if } \int f\,(x)\,d\,x = \frac{x^2}{2}, \int_l^{l_1} f\,(x)\,d\,x = \frac{l^2{}_1 - l^2}{2}.$$

The converse of one of the foregoing differential formulæ shows that the integral of the sum of several differentials, is equal to the sum of the integrals of each of the differentials.

The differentials of the trigonometrical functions already tabulated will be explained by consideration of Fig. 762, in which

$\mathrm{C\,A} = \mathrm{C\,P} = \mathrm{C\,Q} =$ radius $= 1$, the arc $\mathrm{A\,P} = x$; $\mathrm{P\,Q} = d\,x$; $\mathrm{P\,M_1} = \sin.\,x$; $\mathrm{C\,M} = \cos.\,x$; $\mathrm{A\,S} = \tan.\,x$, $\mathrm{O\,Q} = \mathrm{N\,Q} - \mathrm{M\,P} = \sin.\,(x + d\,x) - \sin.\,x = d\,\sin.\,x$; $\mathrm{O\,P} = -\,(\mathrm{C\,N} - \mathrm{C\,M}) = -\cos.\,(x + d\,x) + \cos.\,x = -\,d\,\cos.\,x$, and $\mathrm{S\,T} = \mathrm{A\,T} - \mathrm{A\,S} = \tan.\,(x + d\,x) - \tan.\,x = d\,\tan.\,x$.

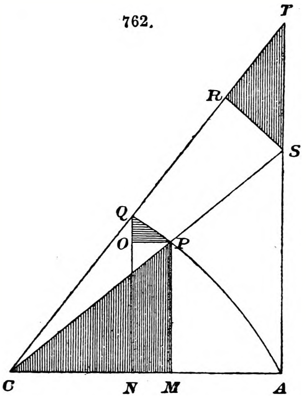
The influence of errors in the arc or angle upon the sine increases as cos. x becomes greater, or as the arc or angle is smaller, while on the contrary the influence upon the cosine increases with increase of the sine, or the nearer the arc approaches to $\frac{\pi}{2}$. The differential of the cosine has the opposite sign from that of the arc, for increase of x, corresponds to a decrease of cos. x, and *vice versâ.* Inversion of the differential formulæ will therefore give the integral, thus

$$\int \cos. x \, d x = \sin. x$$

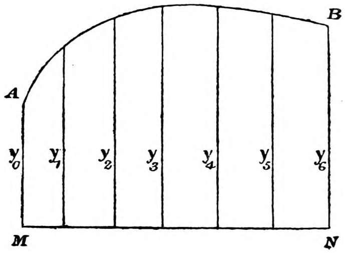
$$\int \frac{d x}{\cos.^2 x} = \tan. x.$$

By integrating the differential $d\,(u\,v) = u\,d\,v + v\,d\,u$ there results $u\,v = \int u\,d\,v + \int v\,d\,u$, and the following formula is obtained; $\int v\,d u = u\,v - \int u\,d v$, known as integrating by parts. This rule is always applicable if the integral $\int v\,d\,u$ is unknown, and integral $\int u\,d\,v$ is known.

762.



763.



Every integral of the form $\int y\,d\,x = \int f\,(x)\;d\,x$ may be put equal to the area of a surface S, consequently if the integration cannot be effected by known rules, it can be arrived at with sufficient approximation for practical purposes by well-known geometrical devices. Indeed, the integration of areas, although an operation frequently involving intense thought to the mathematician, is performed by the practical man geometrically without the least reference to the calculus, a sufficient reason for the preference generally shown to geometrical over analytical investigations in the calculus.

In order to find the area of a surface, Fig. 763, having a base M N = x, and divided by an uneven number of ordinates $y_0, y_1, y_2 \ldots\ldots y_n$ into an even number of strips, we have Simpson's rule. The formula for the area of a surface divided in n strips is

$$S = [y_0 + y_n + 4\,(y_1 + y_3 + \ldots\ldots + y_{n-1}) + 2\,(y_2 + y_4 + \ldots + y_{n-2})]\,\frac{x}{3\,n},$$

and the mean height is

$$y = \frac{y_0 + y_n + 4\,(y_1 + y_3 + \ldots\ldots + y_{n-1}) + 2\,(y_2 + y_4 + \ldots + y_{n-2})}{3\,n}$$

in which n must be an even number.

This formula can be used for the determination of an integral $\int_{l}^{l_1} y\,d\,x = \int_{l}^{l_1} \phi\,(x)\,d\,x$, if $x = l_1 - l$ be divided into an even (n) number of parts. The ordinates

$$y_0 = \phi\,(l);\; y_1 = \phi\left(l + \frac{x}{n}\right);\; y_2 = \phi\left(l + \frac{2\,x}{n}\right);\; y_3 = \phi\left(l + \frac{3\,x}{n}\right)$$

are to be calculated up to $y_n = \phi\,(x)$, and these values substituted in the formula

$$\int_{l}^{l_1} y\,d\,x = \int_{l}^{l_1} \phi\,(x)\,d\,x =$$

$$[\,y_0 + y_n + 4\,(y_1 + y_3 + \ldots + y_{n-1}) + 2\,(y_2 + y_4 + \ldots + y_{n-2})]\,\frac{l_1 - l}{3\,n}.$$

The rectification of a curve, or the deduction, from its equation $y = f\,(x)$ between the coordinates A M = x and M P = y, Fig. 752, of an equation between the arc A P = s and one of the coordinates, is performed by determining the differential of the arc A P of the curve, and then taking its integral. By Pythagoras' theorem $d\,s^2 = d\,x^2 + d\,y^2$ and $d\,s = \sqrt{d\,x^2 + d\,y^2}$, hence the arc of the curve itself is $s = \int \sqrt{d\,x^2 + d\,y^2}$.

The perpendicular to the tangent P T, Fig. 764, is normal also to the curve at the tangent point, because the tangent gives the direction of the curve at this point. That part of the line P O between the tangent point and the abscissa-axis is termed the normal, and the projection M O of this line on the abscissa-axis the sub-normal. Because the angles M P O and P T M are identical, $M\,O = M\,P \,.\, \tan.\, a$, and the sub-normal $y \tan.\, a = \frac{y\,d\,y}{d\,x}$.

If to a point Q infinitely near the point P another normal Q C be drawn, these lines intersect in the centre C of a circle, which is termed the circle of curvature, and these normals, that is those parts of them between the circle and the centre, are termed the radii of curvature. The circle itself is termed the osculatory circle.

Denoting the radius $C\,P = C\,Q$ by the letter r, the arc A P of the curve by s, and the tangential angle P T M by a, since $P\,Q = C\,P \times$ arc of angle P C Q, $d\,s = -\,r\,d\,a$, and the radius of curvature, consequently $r = -\frac{d\,s}{d\,a}$.

a can be determined from the equation of the coordinates by putting $\tan.\, a = \frac{d\,y}{d\,x}$; and as $d \tan.\, a = \frac{d\,a}{\cos.^2 a}$, and $\cos.\, a = \frac{d\,x}{d\,s}$, $d\,a = \cos.^2 a \times d \tan.\, a = \frac{d\,x^2}{d\,s^2} \times d \tan.\, a$; and

$$r = -\frac{d\,s}{\cos.^2 a \times d \tan.\, a} = -\frac{d\,s^3}{d\,x^2 \times d \tan.\, a}.$$

When the curve is convex,

$$r = +\frac{d\,s}{d\,a} = +\frac{d\,s^3}{d\,x^2 + d \tan.\, a},$$

whilst for a point of inflexion $r = \infty$.

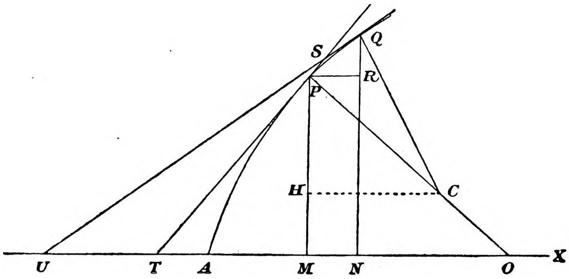
The coordinates $A\,O = u$ and $O\,C = v$ of the centre of curvature are given by

$$u = A\,M + H\,C = x + C\,P \sin.\, C\,P\,H \text{ or } x + r \sin.\, a,$$

and

$$v = O\,C = M\,P - H\,P = y - C\,P \cos.\, C\,P\,H \text{ or } y - r \cos.\, a.$$

764.



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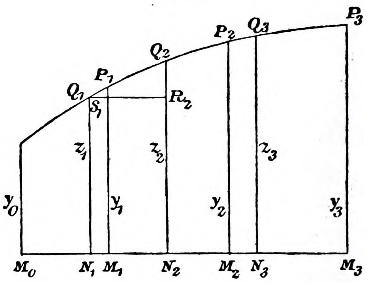


The line or curve formed by these centres of curvature is termed the evolute of the curve A P.

If in a surface $M_0\,M_3\,P_3\,P_0$, Fig. 765, there are given the four coordinates $M_0\,P_0 = y_0$ to $M_3\,P_3 = y_3$, all equidistant from one another, the surface may be calculated in a very simple manner.

Denoting the base by x_3 or $M_0\,M_3$, three equidistant ordinates $z_1\,z_2\,z_3$ are to be interpolated between y_0 and y_3. The surface S then

$$= (\tfrac{1}{2}\,y_1 + z_1 + z_2 + z_3 + \tfrac{1}{2}\,y_3)\,\frac{x_3}{4};\ \text{but}\ \frac{z_1 + z_2 + z_3}{3} = \frac{y_1 + y_2}{2}$$

and

$$S = [y_0 + 3\,(y_1 + y_2) + y_3]\,\frac{x_3}{8} \text{ and } y_m = \frac{y_0 + 3\,(y_1 + y_2) + y_3}{8}.$$

This formula can be employed when the surface is divided into an uneven number of strips, the foregoing formula for y_m applying to an even number. So that if $y_0 = \phi\,(l)$; $y_1 = \phi\,\frac{(2\,l + l_1)}{3}$; $y_2\,\phi\,\frac{(l + 2\,l_1)}{3}$; and $y_3 = \phi\,(l_1)$ are four known or given values of $y = \phi\,(x)$,

$$\int_l^{l_1} y\,d\,x = \int_l^{l_1} \phi\,(x)\,d\,x \text{ approximately} = [y_0 + 3\,(y_1 + y_2) + y_3]\,\frac{l_1 - l}{8}.$$

The following table represents a number of integrals with their ultimate forms, and will be found of the utmost use in reducing integrals which may be arrived at in practice, or in suggesting methods of reduction;—

Differential to be Integrated.	Integral.
$\frac{x^m\,d\,x}{a + b\,x}$	$\int \frac{d\,x}{a + b\,x} = \frac{\log.\,(a + b\,x)}{b}$
$\frac{x^m\,d\,x}{(a + b\,x)^n}$	$\int \frac{d\,x}{(a + b\,x)^n} = \frac{-1}{(n - 1)\,b\,(a + b\,x)^{n-1}}$
$\frac{d\,x}{x^m\,(a + b\,x)^n}$	$x = 1_1\,y$ gives $\frac{-\,y^{m+n-2}\,d\,y}{(b + a\,y)^n}$
$\frac{d\,x}{(a + b\,x^2)^n}$	$\int \frac{d\,x}{a - b\,x^2} = \frac{1}{2\sqrt{a\,b}} \log.\,\frac{\sqrt{a} + x\sqrt{b}}{\sqrt{a} - x\sqrt{b}}$
$\frac{d\,x}{x^m\,(a + b\,x^2)^n}$	$x = \frac{1}{y}$ gives $\frac{-\,y^{m+2n-2}\,d\,y}{(b + a\,y^2)^n}$
$\frac{x^m\,d\,x}{\sqrt{a + b\,x}}$	$\int \frac{d\,x}{\sqrt{a + b\,x}} = \frac{2\sqrt{a + b\,x}}{b}$
$\frac{d\,x}{x^m\sqrt{a + b\,x^2}}$	$x = \frac{1}{y}$ gives $\frac{-\,y^{m-1}\,d\,y}{\sqrt{a\,y + b}}$
$x^m\sqrt{(a\,x + b\,x^2)}\,d\,x$	$\int \sqrt{(a\,x + b\,x^2)}\,d\,x = \frac{(2\,b\,x + a)\sqrt{a\,x + b\,x^2}}{4\,b} - \frac{a^2}{8\,b}\int \frac{d\,x}{\sqrt{a\,x + b\,x^2}}$

The multiplication of more intricate forms is useless, since it is far preferable to determine such questions geometrically, than to run the risk of miscalculation or clerical error.

Sufficient has been said upon this subject to enable those requiring further information to refer to the works of Todhunter, Boole, and De Morgan.

Various machines have been from time to time devised, for the purpose of ascertaining approximations to forms, that cannot be integrated analytically without immense labour.

The most important of these apparatus is that devised by Wm. Thomson, of Glasgow University, and described in the Proceedings of the Royal Society, 1876.

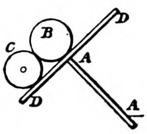
The kinematic principle for integrating $y\,d\,x$, which is used in the instruments known as Morin's dynamometer and Sang's planimeter, involves one element of imperfection. This imperfection consists in the sliding action, which the edge wheel or roller is required to take in conjunction with its rolling action, which alone is desirable for exact communication of motion from the disc or cone to the edge roller. Amsler's polar planimeter, although different in its main features of principle, and mode of action, from the instruments just referred to, ranks with them in involving the like imperfection, or requiring to have a sidewise sliding action of its edge rolling wheel, besides the desirable rolling action on the surface, which imparts to it its revolving motion, a surface which in this case is not a disc or cone, but is the surface of the paper, or any other plane face, on which the map or other plane diagram to be evaluated in area is drawn.

Clerk Maxwell succeeded in devising a new form of planimeter, or integrating machine, with a kinematic action depending on the mutual rolling of two equal spheres, each on the other, and also offered a suggestion, proposing the attainment of the desired conditions of action, by the mutual rolling of a cone and cylinder with their axes at right angles.

The idea of using pure rolling, instead of combined rolling and slipping, was extended by Thomson, who succeeded in devising a new kinematic method, capable of being introduced and combined in several ways to produce important results.

The new principle consists primarily in the transmission of motion from a disc or cone, Figs. 766 and 767, to a cylinder, by the intervention of a loose ball, which presses by its gravity on the disc and cylinder, or on the cone and cylinder, as the case may be, the pressure being sufficient to give the necessary frictional coherence at each point of rolling contact; and the axis of the disc or cone and that of the cylinder, being both held fixed in position by bearings in stationary framework, and the arrangement of these axes being such, that when the disc or the cone and the cylinder are kept steady, or without rotation on their axes, the ball can roll along them in contact with both, so that the point of rolling contact between the ball and the cylinder, shall traverse a straight line on the cylindric surface, parallel, necessarily, to the axis of the cylinder; and so that, in the case of a disc being used, the point of rolling contact of the ball with the disc, shall traverse a straight line passing through the centre of the disc, or that in case of a cone being used, the line of rolling contact of the ball on the cone shall traverse a straight line on the conical surface, directed necessarily towards the vertex of the cone. It will thus readily be seen that, whether the cylinder and the disc or cone be at rest, or revolving on their axes, the two lines of rolling contact of the ball, one on the cylindric surface and the other on the disc or cone, when both are considered as lines traced out in space fixed relatively to the framing of the whole instrument, will be two parallel straight lines, and that the line of motion of the ball's centre will be straight and parallel

766.



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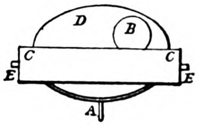


to them. For facilitating explanations, the motion of the centre of the ball along its path parallel to the axis of the cylinder, may be called the ball's longitudinal motion.

For the integration of $y\,dx$, the distance of the point of contact of the ball with the disc or cone, from the centre of the disc or vertex of the cone in the ball's longitudinal motion, is to represent y, while the angular space turned by the disc or cone from any initial position represents x; and then the angular space turned by the cylinder will, when multiplied by a suitable constant numerical coefficient, express the integral in terms of any required unit for its evaluation.

The longitudinal motion may be imparted to the ball, by having the framing of the whole instrument so placed that, the lines of longitudinal motion of the two points of contact and of the ball's centre, which are three straight lines mutually parallel, shall be inclined to the horizontal, sufficiently to make the ball tend decidedly to descend along the line of its longitudinal motion, and then regulating its motion by an abutting controller, which may have at its point of contact, where it presses on the ball, a plane face perpendicular to the line of the ball's motion. Otherwise the longitudinal motion may, for some cases, preferably be imparted to the ball by having the direction of that motion horizontal, and having two controlling flat faces acting in close contact, without tightness, at opposite extremities of the ball's diameter, which at any moment is in the line of the ball's motion, or is parallel to the axis of the cylinder.

It is worthy of notice that, in the case of the disc, ball, and cylinder integrator, no theoretical nor important practical fault in the action of the instrument would be involved in any deficiency of perfect exactitude, in the practical accomplishment of the desired condition, that the line of motion of the ball's point of contact with the disc should pass through the centre of the disc.

The plane of the disc may suitably be placed inclined to the horizontal at some such angle as 45°. An additional operation, important for some purposes, is effected as suggested by W. Thomson, by arranging that the machine shall give a continuous record of the growth of the integral, by introducing additional mechanisms suitable for continually describing a curve such that, for each point of it, the abscissa shall represent the value of x, and the ordinate shall represent the integral attained from $x = 0$ forward to that value of x. This is effected in practice by having a cylinder axised on the axis of the disc, a roll of paper covering this cylinder's surface, and a straight bar situated parallel to this cylinder's axis, and resting with enough of pressure on the surface of the primary registering or the indicating cylinder, which is actuated by its contact with the ball to make it have sufficient frictional coherence with that surface, and having this bar made to carry a pencil, or other tracing point, marking the desired curve on the secondary registering or the recording cylinder. As from the nature of the apparatus, the axis of the disc and of the secondary registering or the recording cylinder, ought to be steeply inclined to the horizontal, and as, therefore, this bar, carrying the pencil, has the line of its length and of its motion alike steeply inclined with that axis, it is advisable to have a thread attached to the bar and extending off in the line of the bar to a pulley, passing over the pulley, and having suspended at its other end a weight which will be just sufficient to counteract the tendency of the rod, in virtue of gravity, to glide down along the line of its own slope, so as to leave it perfectly free to be moved up or down, by the frictional coherence between itself and the moving surface of the indicating cylinder, worked directly by the ball.

To calculate $\int \phi(x)\,\psi(x)\,dx$, the rotating disc is to be displaced from a zero or initial position, through an angle equal to $\int_0^x \phi(x)\,dx$, while the rolling globe is moved so as always to be at a distance from its zero position equal to $\psi(x)$. This being done, the cylinder obviously turns through an angle equal to $\int_0^x \phi(x)\,\psi(x)\,dx$, and thus solves the problem.

One way of giving the required motions to the rotating disc and rolling globe is as follows;—

On two pieces of paper draw the curves $y = \int_0^x \phi(x)\,dx$, and $y = \psi(x)$. Attach these pieces of paper to the circumference of two circular cylinders, or to different parts of the circumference of one cylinder, with the axis of x in each in the direction perpendicular to the axis of the cylinder. Let the two cylinders be geared together, so that their circumference shall move with equal velocities. Attached to the framework let there be, close to the circumference of each cylinder, a slide or guide-rod to guide a movable point, moved by the hand of an operator, so as always to touch the curve on the surface of the cylinder, while the two cylinders are moved round.

Two operators will be required, as one operator could not move the two points so as to fulfil this condition, unless the motion were very slow. One of these points, by proper mechanism, gives an angular motion to the rotating disc equal to its own linear motion, the other gives a linear motion equal to its own to the centre of the rolling globe.

The machine thus described is immediately applicable to calculate the values H_1, H_2, H_3, etc. of the harmonic constituents of a function $\psi(x)$ in the generalization of Fourier's simple harmonic analysis, in the conduction of heat in the sphere and the cylinder. Thus if

$$\psi(x) = H_1\,\phi_1(x) + H_2\,\phi_2(x) + H_3\,\phi_3(x) + \text{etc.}$$

be the expression for an arbitrary function ψx, in terms of the generalized harmonic functions $\phi_1(x)$, $\phi_2(x)$, $\phi_3(x)$, etc., these functions being such that

$$\int_0^l \phi_1(x)\,\phi_2(x)\,dx = 0,\ \int_0^l \phi_1(x)\,\phi_3(x)\,dx = 0,\ \int_0^l \phi_2(x)\,\phi_3(x) = 0,\ \text{etc.},$$

$$H_1 = \frac{\int_0^l \phi_1(x)\,\psi(x)\,dx}{\int_0^l \{\phi_1(x)\}^2\,dx},$$

$$H_2 = \frac{\int_0^l \phi_2(x)\,\psi(x)\,dx}{\int_0^l \{\phi_2(x)\}^2\,dx},\ \text{etc.}$$

In the physical applications of this theory, the integrals which constitute the denominators of the formulæ for H_1, H_2, etc., are always to be evaluated in finite terms, by an extension of Fourier's formula for $\int_0^x x\, u_i^2\, d\, x$ of his problem of the cylinder. The integrals in the numerators are calculated with great ease by aid of the machine worked in the manner described above.

The great practical use of this machine is to perform the simple harmonic Fourier-analysis for tidal, meteorological, and perhaps even astronomical observations. It is the case in which

$$\phi\,(x) = \frac{\sin.}{\cos.}\,(n\, x);$$

and the integration is performed through a range equal to $\frac{2\, i\, \pi}{n}$, i any integer, that gives this application. In this case the addition of a simple crank mechanism, to give a simple harmonic angular motion to the rotating disc in the proper period $\frac{2\,\pi}{n}$, when the cylinder bearing the curve $y = \psi\,(x)$ moves uniformly, supersedes the necessity for a cylinder with the curve $y = \phi\,(x)$ traced on it, and an operator keeping a point always on this curve in the manner described above.

The accuracy of the apparatus will depend essentially on the accuracy of the circular cylinder, of the globe, and of the plane of the rotating disc used in it. For each of the three surfaces a much less elaborate application of the method of scraping than that by which Whitworth has given a true plane with such marvellous accuracy, suffices for the practical requirements of the instrument now proposed.

Every linear differential equation of the second order may be reduced to the form

$$\frac{d}{d\, x}\left(\frac{1}{P}\frac{d\, u}{d\, x}\right) = u \qquad (1)$$

where P is any given function of x.

On account of the great importance of this equation in mathematical physics in estimating the vibrations of a non-uniform stretched cord, of a hanging chain, of water in a canal of non-uniform breadth and depth, of air in a pipe of non-uniform sectional area, conduction of heat along a bar of non-uniform section or non-uniform conductivity, or Laplace's differential equation of the tides, its practical solution without labour has long been sought.

Methods of calculation such as those used by Laplace are very laborious, too laborious unless a serious object is to be attained by calculating out results with minute accuracy. This is done with the integrator; for if

$$\left.\begin{aligned} u_2 &= \int_0^x P\,(C - \int_0^x u_1\, d\, x)\, d\, x, \\ u_3 &= \int_0^x P\,(C - \int_0^x u_2\, d\, x)\, d\, x, \end{aligned}\right\} \qquad (2)$$
$$\text{etc.,}$$

where u_1 is any function of x, to begin with, as for example $u_1 = x$; then u_2, u_3, etc., are successive approximations converging to that one of the solutions of (1) which vanishes when $x = 0$. Let the integrator be applied to find $C - \int_0^x u_1\, d\, x$, and let its result feed, as it were, continuously a second machine, which shall find the integral of the product of its result $P\, d\, x$. The second machine will give out continuously the value of u_2. Use again the same process with u_2 instead of u_1 and then u_3, and so on.

After thus altering, as it were, u_1 into u_2 by passing it through the machine, then u_2 into u_3 by a second passage through the machine, and so on, the thing will, as it were, become refined into a solution which will be more and more nearly rigorously correct, the oftener we pass it through the machine. If u_{i+1} does not sensibly differ from u_i, then each is sensibly a solution.

Compel agreement between the function fed into the double machine, and that given out by it. This is to be done by establishing a connection which shall cause the motion of the centre of the globe of the first integrator of the double machine, to be the same as that of the surface of the second integrator's cylinder. The motion of each will thus be necessarily a solution of (1).

Take two integrators, and connect the fork which guides the motion of the globe of each of the integrators, by proper mechanical means, with the circumference of the other integrator's cylinder. Then move one integrator's disc through an angle $= x$, and simultaneously move the other integrator's disc through an angle always $= \int_0^x P\, d\, x$, a given function of x. The circumference of the second integrator's cylinder, and the centre of the first integrator's globe, move each of them through a space which satisfies the differential equation (1).

To prove this, let at any time g_1, g_2 be the displacements of the centres of the two globes from the axial lines of the discs; and let $d\, x$, $P\, d\, x$ be infinitesimal angles turned through by the two discs. The infinitesimal motions produced in the circumference of two cylinders will be

$$g_1\, d\, x \text{ and } g_2\, P\, d\, x.$$

But the connections pull the second and first globes through spaces, respectively equal to those moved through by the circumferences of the first and second cylinders. Hence

$$g_1\, d\, x = d\, g_2, \text{ and } g_2\, P\, d\, x = d\, g_1;$$

and eliminating g_2,

$$\frac{d}{d\, x}\left(\frac{1}{P}\frac{d\, g_1}{d\, x}\right) = g_1,$$

which shows that g_1 put for u satisfies the differential equation (1).

The machine gives the complete integral of the equation with its two arbitrary constants. For, for any particular value of x, give arbitrary values G_1, G_2. That is to say mechanically; disconnect the forks from the cylinders, shift the forks till the globes' centres are at distances G_1, G_2 from the axial lines, then connect, and move the machine. For this value of x,

$$g_1 = G_1, \text{ and } \frac{d g_1}{d x} = G_2 P\,;$$

that is, arbitrary values for g_1 and $\frac{d g_1}{d x}$ are secured by the arbitrariness of the two initial positions G_1, G_2 of the globes.

The instrument can also be applied to the mechanical integration of the general linear differential equation of any order with variable coefficients, by taking any number i of integrators, and making an integrating chain of them.

Until it is desired actually to construct a machine for thus integrating differential equations of the third or any higher order, it is not necessary to go into details as to plans for mechanical fulfilment of condition (7); it is enough to know that it can be fulfilled by pure mechanism, working continuously in connection with the rotating discs of the train of integrators.

But the integrator may be applied to integrate any differential equation of any order. Let there be i simple integrators; let x_1, g_1, κ_1 be the displacements of disc, globe, and cylinder of the first, and so on for the others. Then

$$g_1 = \frac{d \kappa_1}{d x_1},\ g_2 = \frac{d \kappa_2}{d x_2},\ \text{etc.},$$

and by proper mechanism establish such relations between

$$x_1, g_1, \kappa_1, x_2\, g_2, \text{ etc., that } f^{(1)}\,(x_1, g_1\, \kappa_1, x_2, \ .\ .\ .) = 0, \text{ etc.}$$

Thus $2i-1$ simultaneous equations are solved.

By constructing in steel, as a cam, the surface whose equation is $z = \xi f\,(\xi^2 + \eta^2)$, and repetitions of it, for practical convenience, we have a complete mechanical integration of the problem of finding the free motions of any number of mutually influencing particles, one of the most difficult mathematical problems.

CANALS.

In treating of their construction, canals may be classified in three divisions.

Level canals, or ditch canals, consisting of one reach or pond, which is at the same level throughout. The most economical course is one which nearly follows a contour line, except where opportunities occur of crossing a ridge or a valley to avoid a long circuit.

Lateral canals, which connect two places in the same valley, and in which there is no summit level, the fall taking place in one direction only. A lateral canal is divided into a series of level reaches or ponds, connected by sudden changes of level, at which there are locks. The lift of a single lock ranges from 2 ft. to 12 ft., and is most commonly 8 or 9 ft. Each level reach is laid out on the same principles with a level canal. In fixing the lengths of the reaches and the positions of the locks, economy of water is promoted by distributing a given fall amongst single locks with reaches between them, rather than concentrating the whole fall at one flight of locks.

Canals with summits have to be laid out with a view to economy of works at the passes between one valley and another, and with a view also to the obtaining of sufficient supplies of water at the summit reaches.

An open river is one in which the water is left to take a continuous declivity, uninterrupted by weirs. The towing path required, if horse-haulage is to be employed, is similar to that of a canal. The effect of the current of the stream on the load which one horse is able to draw against it at a walk, may be roughly estimated as load drawn against current = load drawn in still water $\times \left(\frac{3 \cdot 6}{3 \cdot 6 + v}\right)^2$; v being the velocity of the current in feet a second.

A canalized river is one in which a series of ponds or reaches, with a greater depth of water and a slower current than the river in its natural state, have been produced by means of weirs. Each weir on a navigable river requires to be traversed by a lock for the passage of vessels, the most convenient place for which is usually near one end of the weir, next the towing-path bank. River locks differ from canal locks in having no lift-wall, so that the head-gates and tail-gates are of equal height.

Although short portions of a canal may be wide enough for the passage of one boat only, the general width ought to be sufficient to allow two boats to pass each other easily. The depth of water, and sectional area of waterway, should be such as not to cause any material increase of the resistance to the motion of the boat, beyond what it would encounter in open water. The following are the general rules which fulfil these conditions;—

The least breadth at bottom to be twice the greatest breadth of a boat, the least depth of water to be one and a half time the greatest draught of a boat, the least area of waterway to be six times the greatest midship section of a boat. The bottom of the waterway is flat. The sides, when of earth, should not be steeper than 1½ to 1; when of masonry, they may be vertical; but in the case of vertical sides, about 2 ft. additional width at the bottom must be given to enable boats to clear each other, and if the length traversed between vertical sides is great, as much more additional width as may be necessary in order to give sufficient sectional area.

The dimensions of canal boats have been fixed with a view to horse-haulage. The most economical use of horse-power on a canal is to draw heavy boats at low speeds. The heaviest boat that one horse can draw at a speed of from 2 to 2½ miles an hour, weighs, with its cargo, about

105 tons, is about 70 ft. long and 12 ft. broad, and draws about $4\frac{1}{2}$ ft. of water when fully loaded. Smaller boats which a horse can draw at $3\frac{1}{2}$ or 4 miles an hour, are of about the same length, 6 or 7 ft. broad, and draw about $2\frac{1}{2}$ ft. of water.

The following are examples of the extreme and ordinary dimensions of canals, as given by Rankine;—

	Breadth at Bottom.	Breadth at Top Water.	Depth of Water.
	ft.	ft.	ft.
Small canal	12	24	4
Ordinary canal	25	40	5
Large canal	50	110	20

The width of the embankment which carries the towing path is usually about 12 ft. at the top; that of the opposite embankment at least 4 ft., and sometimes 6 ft. Each embankment should have a vertical puddle wall in its centre from 2 to 3 ft. thick.

The surface of the towing path is usually about 2 ft. above the water level. It is made to slope slightly in a direction away from the canal, in order to give a better foothold for the horses, as they draw in an oblique direction. The slopes may be pitched with dry stone from 6 to 9 in. thick.

Leaks in canals may sometimes be stopped by shaking loose sand, clay, lime, or chaff into the water. The particles are carried into the leaks, which they eventually choke by accumulation.

To save time and water expended in shifting boats from one level to another by means of locks, inclined planes are used on some canals. The general arrangement is that the upper and lower reach of the canal, at the places which are to be connected by inclined planes, are deepened sufficiently to admit of the introduction of water-tight iron caissons, or movable tanks, under the boats. Two parallel lines of rails start from the bottom of the lower reach, ascend an inclined plane up to a summit a little above the water level of the upper reach, and then descend down a short inclined plane to the bottom of the upper reach. There are two caissons, or movable tanks on wheels, each holding water enough to float a boat. One of these caissons runs on each line of rails; and they are so connected, by means of a chain, or of a wire rope, running on movable pulleys, that when one descends the other ascends. These caissons balance each other at all times when both are on the long incline, because the boats, light or heavy, which they contain, displace exactly their own weight of water. There is a short period when both caissons are in the act of coming out of the water, one at the upper and one at the lower reach, when the balance is not maintained; and in order to supply the power required at that time, and to overcome friction, a steam engine drives the main pulley, as in the case of fixed engine planes on railways.

Boats may be hauled up on wheeled cradles without using caissons; but this requires a greater expenditure of power. Grahame has proposed a method which would enable a fixed engine to be dispensed with where steamboats are used. It consists in providing each steamer with a windlass, driven by its engine, and the inclined plane simply with a rope, whose upper end is made fast while its lower end is loose. The boat is floated on to the cradle at the bottom of the plane; the loose end of the rope is laid hold of and attached to the windlass, which, being driven by the engine, causes the boat to haul itself up the inclined plane.

Canals are supplied with water from gathering-grounds, springs, rivers, and wells, by the aid of reservoirs and conduits; and their supply involves the questions of rainfall, demand, compensation, already treated of in this Dictionary.

The amount of water required may be estimated to include—

Waste of water by leakage of the channel, repairs, and evaporation a day = area of surface of the canal × $\frac{1}{6}$ of a foot nearly. Current from the higher towards the lower reaches, produced by leakage at the lock gates, a day, from 10,000 to 20,000 cubic ft. in ordinary cases. Lockage, or expenditure of water in passing boats from one level to another.

Let L denote a lockful of water; that is, the volume contained in the lock chamber, between the upper and lower water-levels. B, the volume displaced by a boat. Then the quantities of water discharged from the upper pond, at a lock or a flight of locks, under various circumstances, are shown in the following tables. The sign prefixed to a quantity of water denotes that it is displaced from the lock into the upper reach.

Single Lock.	Lock Found.	Water Discharged.	Lock Left.
One boat descending	Empty	$L - B$	Empty.
" "	Full	$- B$	
Two n boats descending and ascending alternately	Descending full Ascending empty	$n L$	Descending empty. Ascending full.
One boat ascending	Empty or full ..	$L + B$	Full.
Train of n boats descending ..	Empty	$n L - n B$	Empty.
" " ..	Full	$(n - 1) L - n B$	
Train of n boats ascending ..	Empty or full ..	$n L + n B$	Full.
Two trains, each of n boats, the first descending, the second ascending	Full	$(2 n - 1) L$	Full.

Flight of *m* Locks.	Locks Found.	Water Discharged.	Locks Left.
One boat descending	Empty	$L - B$	Empty.
" "	Full	$- B$	
One boat ascending	Empty	$m L + B$	Full.
" "	Full	$L + B$	
Two *n* boats ascending and descending alternately ..	Descending full .. Ascending empty	$m n L$	Descending empty. Ascending full.
Train of *n* boats descending ..	Empty	$n L - n B$	Empty.
" " " ..	Full	$(n - 1) L - n B$	
Train of *n* boats ascending ..	Empty	$(m + n - 1) L + n B$	Full.
" " " ..	Full	$n L + n B$	
Two trains, each of *n* boats, the first descending, the second ascending	Full	$(m + 2n - 2) L$	Full.

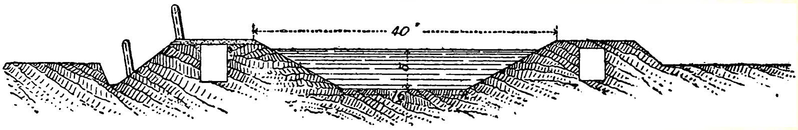
From these calculations Rankine has deduced that single locks are more favourable to economy of water than flights of locks; that at a single lock, single boats ascending and descending alternately cause less expenditure of water than equal numbers of boats in trains; and that, on the other hand, at a flight of locks, boats in trains cause less expenditure of water than equal numbers of boats ascending and descending alternately. For this reason, when a long flight of locks is unavoidable, it is usual to make it double; that is, to have two similar flights side by side, using one exclusively for ascending boats and the other exclusively for descending boats.

Water may be saved at flights of locks by the aid of side ponds, or lateral reservoirs. The use of a side pond is to keep for future use a certain portion of the water discharged from a lock, when the locks below it in the flight are full, which water would otherwise be wholly discharged into the lower reach. If a be the horizontal area of a lock chamber, A that of its side pond, then the volume of water so saved is $L A \div (A + a)$.

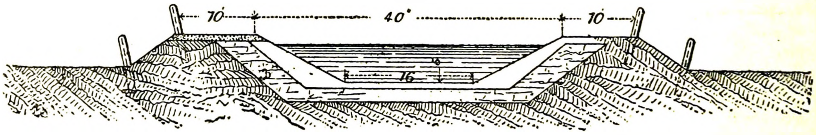
It has been pointed out in this Dictionary that a canal cannot be properly worked without a supply of water calculated to last over the driest season of the year, and in that respect demands great care in investigating the sources of the supply. If no natural lake is available for supply, artificial reservoirs must be constructed, commanding a sufficient area of drainage to supply the loss by leakage, evaporation, and lockage due to the length of the canal, and probable amount of traffic. It is also necessary to consider whether the subsoil of the valley forming the reservoirs, is throughout of so retentive a character as to prevent leakage. Discharge of floods must be provided for by means of waste weirs. As a rule the up traffic consumes a greater quantity of water than the down traffic, because an ascending boat, when entering a lock, displaces a volume of water equal to its submerged contents, and the water displaced, by flowing into the lower reach of the canal, is lost. The lower gates being then closed, the boat is raised, and on passing into the higher reach of the canal, the amount of water displaced on entering is supplied again from the water of the higher reach. A descending boat when entering a lock also displaces a due quantity of water, but this water flows back into the higher reach of the canal, and is there retained when the gates are closed. Falton states that 25-ton boats passing through a lock of 8 ft. lift consume about 163 tons of water in the ascent, and about 103 in the descent.

For barge canals, the sectional area generally adopted is from 24 to 40 ft. in width and 4 to 5 ft. depth. When the soil is sufficiently retentive of water the construction takes the form Fig. 768. But with porous soils the bottom and sides must be puddled, Fig. 769.

768.



769.



In the construction of a canal, gradients, of course, cannot be introduced as upon a road, and the course must follow rigidly the bases of hills and the windings of valleys to preserve a uniform level. It is important to lay out the work in long reaches, and to overcome elevations by accumulated groups of locks in the most advantageous situations; because this plan saves labour in working the canal, and causes fewer stoppages to the traffic. But to prevent waste of water the locks must be placed sufficiently far apart, at about 100 yards, or the intervening part of the canal must have its water capacity increased, so that a descending boat will not let off more water than the area below can receive, without having its level raised so as to lose the surplus water over the waste weirs.

The subject of locks and water-lifts will be found discussed under its proper heading in this Dictionary, and in subsequent pages of this Supplement.

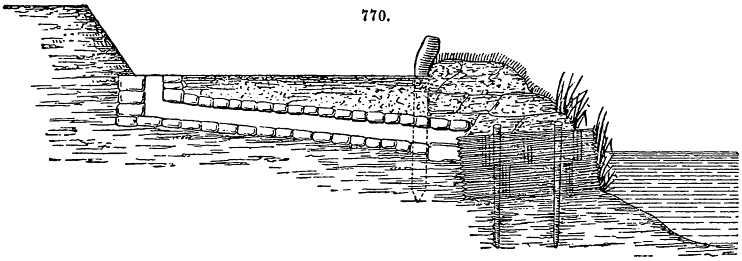
An essential adjunct to a canal is a sufficient number of waste weirs to discharge flood water, which might overflow the towing path. Whenever the canal crosses a stream, a waste weir should be formed in the aqueduct. Waste weirs are placed at the top water level of the canal.

Stop-gates, for the purpose of dividing the canal into isolated reaches, are placed at intervals of a few miles, so that in the event of a breach, these gates may be shut. In larger, or ship canals, these stop-gates are constructed like lock-gates, two pairs of gates being shut in opposite directions. In smaller canals they are constructed of stout planks, slipped into grooves formed at those narrow parts of the canal which occur under road-bridges, or at other contractions. Automatic stop-gates have not met with success.

To admit of repairs after the stop-gates have been closed, the water is drained off through a series of exits, termed offlets, which are pipes placed at the level of the bottom of the canal and fitted with valves. Offlets are generally introduced at aqueducts or bridges crossing rivers, where the contents of the canal can be run off into the bed of the stream, when the stop-gates on both sides are closed, to isolate that part of the canal from which the water is withdrawn.

Provision must be made for the proper drainage of the tow-path. The tow-path should be higher at the side next the canal, and slope with gentle inclination towards the outside. The drainage should be effected through a sky drain, and at intervals passed beneath the tow-path into the canal, Fig. 770.

770.



The protection of the banks at the water line must also receive attention. Both pitching with stone and facing with brushwood are employed, the latter forming an economical as well as efficient protection, if well executed.

Scott Russell has found in trials of propelling boats at high speeds, that the primary wave of displacement produced by the motion of a boat, moves with a velocity due to the depth of water in the canal, being the velocity that is due to gravity, acting through a height equal to the depth of the centre of gravity of the cross section of the channel below the surface of the fluid. This velocity is independent of the form and velocity of the body generating it, and of the width of the canal. A boat raised by a sudden effort to the top of a primary wave can be drawn at 10 miles an hour, with less fatigue to the horses than if drawn at the rate of 6 miles, and the waste is less on the banks of the canal.

A great objection to high speeds in narrow channels is the wasting of the banks by the displacement of water. At moderate speeds the washing is found to extend to not more than 1 ft. 6 in. to 2 ft., that is, to 1 ft. above and below the water line. A facing of stone or brushwood is an effectual remedy.

The employment of steam as a towing power has been found in every way advantageous. There is less rubbing of the vessels against the banks, the power being in the line of pull, and not at an angle, as with horse-traction. The wear and tear of ropes is much reduced, speed is increased, and weather affords no obstacle on the track, as with horses. When a strong wind is blowing athwart the canal, the boats must be taken singly or two at a time; they cannot then be drawn in train. When boats are drawn in train, it is usual to place the heaviest first. A distance of 40 to 50 ft. is the most that can be allowed between two boats, without losing the hold between them that prevents them from sheering from side to side. Although the back wash of the water is more prejudicial to the banks of the canal, its injurious action can be prevented to a great extent by proper facing; and one of the advantages offered by the use of tugs is the cleansing of the slopes of the canal from the deposit of mud, which accumulates at the bottom, and can be easily removed thence by the dredger. On a ship canal, sometimes as many as thirteen loaded vessels of 50 to 100 tons register have been towed by one tug at the rate of 3 to 3½ miles an hour. The heaviest recorded load drawn by one tug has been 1690 tons in three vessels, at 2 miles an hour. The speed is usually restricted with smaller vessels to 4 miles an hour. The cost of towage may be much diminished, and the speed of the boat increased, so as to add considerably to the transport capacity of the canal, by employing the system of cable towage used in Belgium. A wire rope is laid down along the bottom of the canal, the whole length of the course, and is attached at both ends. Tow-boats or tugs, each of which draws a fleet of boats, are provided with engines for giving motion to the clip pulley; any slipping of the cable is thus prevented, the tightness of the clutch of the pulley being automatically regulated by the amount of the load. In working the system, the cable is raised from the bed of the canal, placed in the groove of a drum, provided with suitable grinding and tightening pulleys, on the deck of the tug near the bow; the engine being started, pulls itself along, and with it the tug and accompanying fleet of boats, by means of the cable, which it draws up at the bow, and delivers out at the stern of the vessel.

A. Cunningham, as the result of a long series of experiments conducted for the Indian Govern ment, on the Ganges Canal, close to Roorkee, gives the following. The experiments were confined to channels having trapezoidal sections, with stepped masonry sides, 2 miles long, 150 ft. width of bed, and two rectangular twin channels, in masonry, 932 ft. long, each 85 ft. wide. In all practical treatises results are based on the hypothesis that the motion of water is steady, but these experiments prove that this hypothesis is not even approximately true, and that there are changes in the velocity of the water from instant to instant. The mean surface-velocity curve was found to be represented by the equation $\frac{u^4}{u_0^4} + \frac{y^4}{b^4} = 1$, where b = half the breadth of the channel, y = abscissa of any point on b measured from centre, u_0 = central mean velocity = max. ordinate, u = mean velocity at any point whose abscissa is y = ordinate of mean curve. The arc of this curve, known as a quartic ellipse, taken across the channel, represents the surface discharge = 0·927 × mean central velocity × width of channel.

As to the discharge of canals, A. Cunningham bases the following table of coefficients, for small canals, upon the experiments of Darcy and Bazin; where r = hydraulic mean depth in feet; S = fall of water surface in any distance divided by that distance; v_0 = maximum surface velocity in feet a second; V = mean velocity in feet a second.

TABLE A.—VALUES OF C, FOR USE IN FORMULA $V = C\sqrt{r\,S}$.

Hydraulic Mean Depth in Feet.	Values of C.			
	Bed and Sides of Fine Plaster.	Bed and Sides of Cut Stone or Brickwork.	Bed and Sides Rubble or Boulder Masonry.	Bed and Sides of Earth.
·5	135	110	72	36
·75	139	116	81	42
1·0	141	118	87	48
1·5	143	122	94	56
2·0	144	124	98	62
2·5	145	126	101	67
3·0	145	126	104	70
3·5	146	127	105	73
4·0	146	128	106	76
4·5	146	128	107	78
5·0	146	128	108	80
5·5	146	129	109	82
6·0	147	129	110	84
6·5	147	129	110	85
7·0	147	129	110	86
7·5	147	129	111	87
8·0	147	130	111	88
8·5	147	130	112	89
9·0	147	130	112	90
9·5	147	130	112	90
10·0	147	130	112	91
11·0	147	130	113	92
12·0	147	130	113	93
13·0	147	130	113	94
14·0	147	130	113	95
15·0	147	130	114	96
16·0	147	130	114	97
17·0	147	130	114	97
18·0	147	130	114	98
19·0	147	130	114	98
20·0	147	131	114	98

The general value of C, for use when r is greater than 20 ft., is for—

Bed and sides of fine plaster .. .. $C = \sqrt{\frac{1}{\cdot 0000045\left(10\cdot 16 + \frac{1}{r}\right)}}$.

Bed and sides of cut stone or brickwork .. $C = \sqrt{\frac{1}{\cdot 000013\left(4\cdot 354 + \frac{1}{r}\right)}}$.

Bed and sides of rubble or boulder masonry .. $C = \sqrt{\frac{1}{\cdot 00006\left(1\cdot 219 + \frac{1}{r}\right)}}$.

Bed and sides of earth .. .. $C = \sqrt{\frac{1}{\cdot 00035\left(\cdot 2438 + \frac{1}{r}\right)}}$.

TABLE B.—VALUES OF c, FOR USE IN THE FORMULA $V = c\,v_0$.

Hydraulic Mean Depth in Feet.	Values of c.			
	Bed and Sides of Fine Plaster.	Bed and Sides of Cut Stone or Brickwork.	Bed and Sides Rubble or Boulder Masonry.	Bed and Sides of Earth.
·5	·84	·81	·74	·58
·75	84	·82	·76	·63
1·0	·85	·82	·77	·65
1·5	·85	·82	·78	·69
2·0	·85	·83	·79	·71
2·5	·85	·83	·79	·72
3·0	·85	·83	·80	·73
3·5	·85	·83	·80	·74
4·0	·85	·83	·81	·75
5·0	·85	·83	·81	·76
6·0	·85	·84	·81	·77
7·0	·85	·84	·81	·78
8·0	·85	·84	·81	·78
9·0	·85	·84	·82	·78
10·0	·85	·84	·82	·78
11·0	·85	·84	·82	·78
12·0	·85	·84	·82	·79
13·0	·85	·84	·82	·79
14·0	·85	·84	·82	·79
15·0	·85	·84	·82	·79
16·0	·85	·84	·82	·79
17·0	·85	·84	·82	·79
18·0	·85	·84	·82	·79
19·0	·85	·84	·82	·79
20·0	·86	·84	·82	·80

$$c = \frac{C}{C + 25\cdot3}.$$

Table A must be used when estimating the probable discharge of a contemplated canal; Table B, of a canal actually running. In the latter case, twenty separate measurements should be made, and the arithmetic mean be taken as the average value of the central surface-velocity, v_0.

For larger canals, Table B would not be reliable, and the mean velocities past a great number of verticals in the same cross section, should be measured, either with velocity-rods or with a current-meter. A rod reaching from the surface to nearly the bed affords a fair measurement of the mean velocity in any plane. The rod may be simply a sheet-tin tube, 1 in. in diameter. The lower end is loaded, or formed of a round bar of iron, of such a length that its weight almost submerges the tube to the depth desired, finer adjustment being effected by the addition of small shot, in still water. About 2 or 3 in. is left projecting out of the water, and the mouth sealed with a disc of tin. The velocity is timed by the passage of the float under ropes stretched at intervals across the water.

CARPENTRY.

Carpentry is the science of combining timber to support weight, or to resist pressure; its theory is founded on that branch of mechanical science which informs us of the laws of strains in systems of framing, and on the other hand treats of the strength or resistance of materials. Timber can be preserved in the form given to it, only by careful study of the stresses and strains to which it is subject, according to the laws of mechanics, and the strength of the material.

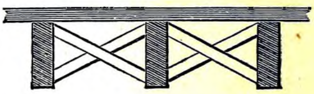
To be able to determine the dimension or scantling of a piece of timber, is of the utmost importance to the carpenter, in order that his work shall be capable of sustaining the weight or pressure likely to be brought upon it. The irregular nature of timber has been a great impediment to the compilation of rules or tables, but the difference in good timber is scarcely perceptible when resistance to flexure only is taken into consideration, as the laws relating to this result from actual experience, and have been accurately determined.

Stiffness in timber is the most important quality to the carpenter, as the material is rarely exposed to breaking strains.

The subject of flooring has been entered upon under the article of Construction, p. 1039 of this Dictionary. The timbers supporting the flooring boards, as well as the ceiling joists, are termed the naked flooring; of this there are three classes, single-joisted floors, double floors, and framed floors; the single-joisted floor has been previously described as consisting of only one series of joists, in which every third or fourth joist may be made deeper, and the ceiling joists are fixed to the deep joists, crossing them at right angles. This method may be used where there is not space for a double floor. By this arrangement, there is very little increase in depth, but considerable gain in imperviousness to sound. The double floor consists of three series of joists, ceiling, bridging, and binding joists. The binding joists support the floor, the bridgers are notched into the upper side of them, and the ceiling joists are notched into the under side or framed between them, the former being the preferable method. Framed floors differ from these double floors in having frames of timber for the binding joists. Double or framed floors are weaker than single floors, comparison being made by the quantity of timber employed, but single floors of long bearing are likely to warp, and disfigure the ceiling, hence they are used only in inferior buildings; for short bearings where a good ceiling is required a double floor should be used, but with long bearings framed floors are preferable. Robinson has experimentally proved single-joisted floors to be stronger than framed floors, but Hurst has pointed out that these experiments were conducted on a smaller scale than that in practice, and the difference is probably not so great, because the girders of the framed floors are not so much weakened by mortises. Hurst gives 1 cwt. a foot of area, exclusive of the weight of the floor itself, as ample allowance for the probable load on an ordinary dwelling-house floor; and 2 cwt. a foot of area, in most cases, for warehouses and factory floors. The joists of the single floor should be thin and deep, with sufficient thickness for the nailing down of the boards. In cases where the joists cannot be supported on the wall, a piece of timber, termed a trimmer, is inserted between two of the nearest joists having a proper bearing, and the ends of the joists to be supported are mortised into this trimmer. The dimension of trimmers may be found by the same rule as those for binders, the length of the joists framed into the trimmer being equal to the distance apart in binders.

The two joists which support the trimmer are termed trimming joists, and must be stronger than the common joists; it is usual to add $\frac{1}{8}$ of an inch to the thickness of the trimming joist for each joist supported by the trimmer. When the bearing exceeds 8 ft., the single joisting should be strutted to prevent the joists turning or twisting sideways, and when the bearing exceeds 12 ft., two rows of struts will be required. Another row of struts should be added for each increase of 4 ft. in bearing. These struts should be in a continuous line across the floor. Boardings put in tightly are a sufficient strut, and simply nailed, are better than keys mortised into the joists. The best method known is Herringbone Strutting, Fig. 771. The pieces are usually about 2 in. square, and are nailed to the joists at the ends. If the joists shrink, these struts do not become loose, and are an essential advantage in making a good ceiling. For ordinary purposes single joists may be used to any extent if timber can be obtained of sufficient depth; where, however, the bearing exceeds 12 ft., the ceiling will not be perfect, and in single-joisted floors sound passes freely.

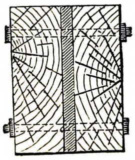
771.



The chief support of a framed floor, the girders, are often limited in their depth by the size of the timber; two cases of scantling must therefore be considered. To find the depth of the girder for the floor of a dwelling-house, when the length of bearing and breadth are given, Hurst gives the following rule;—Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied, by 4·2 for fir, or by 4·34 for oak, will give the depth required in inches. To find the breadth, when the length of bearing and depth are given, the square of the length in feet is to be divided by the cube of the depth in inches; and the quotient multiplied by 0·74 for fir, or by 0·82 for oak, to give the breadth in inches. The girders in these rules are supposed to be 10 ft. apart, and this distance should never be exceeded; if the distance is less the breadth of the girder may be reduced proportionately; girders for long bearings should be as deep as possible. The small extra space required by the girders is of far less disadvantage than a defective ceiling or a shaking floor. These rules do not apply to warehouse or other floors which have to sustain heavy loads, but the strength of these girders should be calculated by the rules previously given in this Dictionary, p. 1040. Broad girders are often sawn down the middle, and bolted together with the sawn sides outwards. The girder, Fig. 772, is supposed to be treated in this manner, which not only gives an opportunity of examining the centre of the tree, but reduces the size of the timber, so that it dries sooner and has less liability to rot. Slips should be inserted between the halves to allow of circulation of the air. This operation does not of course increase the strength of the girders but greater reliance can be placed on the work.

For bearings exceeding 22 ft., it is difficult to obtain timber of sufficient size for girders, and it is then usual to truss them. Figs. 773 and 774 may be ingenious but are of little use; these forms are to be avoided. The fir girder trussed with oak gains in strength merely the difference of compressibility between the two woods, and unless the truss be well fitted, the strength is reduced. Iron trusses fail unless tied to prevent the truss from spreading, for these trusses occasion enormous compression of the timber at the abutments.

772.



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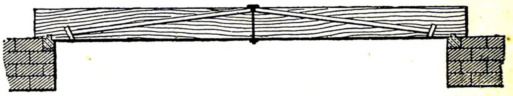

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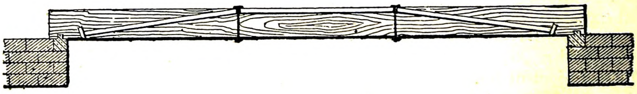


In Barlow's experiments on trusses of the forms of Figs. 773 and 774, the girder having a king bolt and two truss pieces appeared to give a slight advantage, but the three-length truss was weaker than the untrussed pieces. Where the depth is limited, and the bearing considerable, wrought-iron should be employed. A timber girder may be strengthened, without increase of depth, by bolting on each side a plate of wrought iron, or by placing a single plate or flitch of iron between two planks or a beam cut down the middle and reversed.

Experiments made at the Royal Arsenal, Woolwich, in 1859, show that there is some advantage in this combination. Hurst gives the following formula for the breaking weight of beams with iron flitches as described—

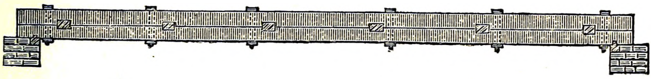
$$W = \frac{D^2}{L}(C\,B + 30\,t);$$

where B and D are the breadth and depth of the wood in inches, t the thickness of the iron flitch in inches, L the length between the supports in feet, and W the breaking weight at the middle in cwts. C is a constant for the kind of timber, as follows;—

	Values of C.		Values of C.
Teak	4·006	Baltic fir	3·024
English or Baltic oak	3·662	American pine	2·774
Canadian oak	3·173	Cedar	2·219

Where iron cannot be obtained except at considerable expense, deep girders may be built, and the most simple method consists in bolting two pieces together with keys between. The keys are to prevent the timbers sliding upon one another, and the joints should be near the middle of the depth, Fig. 775. The total thickness of all the keys should be one-third the depth of the girder, and the breadth of each key should be about twice the thickness. Hoops may be substituted for bolts, the girder being then cut smaller towards the ends to admit of driving in the hoops perfectly tight. In Fig. 776 the timbers are tabled or indented together, instead of being keyed; the upper part of the girder may be in two pieces. The sum of the depths of the indents should not be less than two-thirds of the depth of the complete girder. The upper member of the girder may be bent to a curve, and secured from springing by bolts or straps. Considerable stiffness is gained by bending beams in this manner, which admits of building beams of any depth and of the required length, by breaking the joints or so arranging them that they are not coincident in the two members. The bent pieces should be in thickness about $\frac{1}{50}$ of the length of bearing, but they should not exceed in depth half that of the girder. Where timber cannot be obtained of sufficient length, care should be taken to have no joints in the middle of the length in the lower part of the girders. Joints should be indented or fished; examples of these methods of jointing are given at p. 2168 of this Dictionary. To find the dimension of these girders, multiply $1\frac{1}{2}$ times the area of the floor supported in feet, by the length of the bearing of the girder in feet, divide the product by the square of the depth in inches, and the result will be the breadth of the girder in inches.

775.



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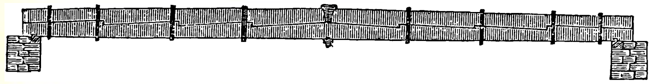

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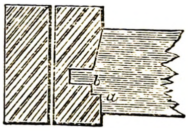

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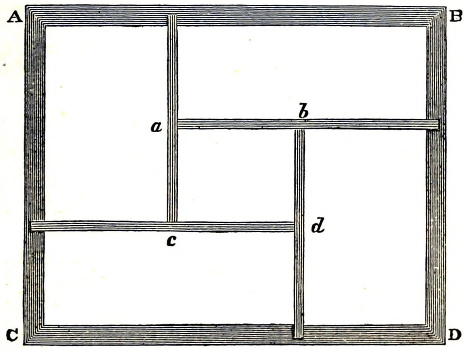

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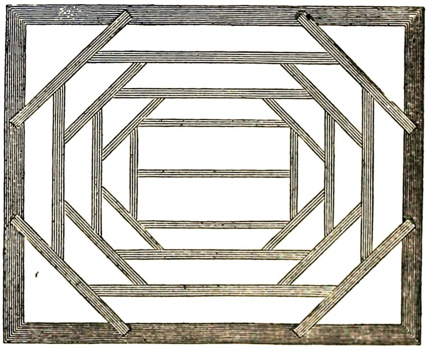


Hurst suggests that it would be advantageous to make each girder only half the breadth given by this rule, and to limit the distance apart to 5 ft.; to bridge the upper floor joists over the girders, and notch the ceiling joists to the under side of them, and to omit the binding joists. This method would greatly increase the strength and stiffness, and be preferable in point of economy, but would require a greater depth of flooring.

Beams should not be built into the wall, but an open space should be left round their ends, by either turning an arch, or laying a sill stone.

Binders must vary in depth according to the depth of the floor. Rules for scantling are given at p. 1040 of this Dictionary. Binding joists should be framed into girders, Fig. 777, so that both of the bearing parts *a* and *b* should fit the corresponding parts of the mortise; the tenon to be about one-sixth of the depth and at about one-third of the depth from the lower side.

Bridging joists follow the same rule as single joists. They are usually not more than 2 in. in thickness, except for ground-floors, in which case 1 in. may be added to the breadth, to allow for decay arising from want of ventilation.

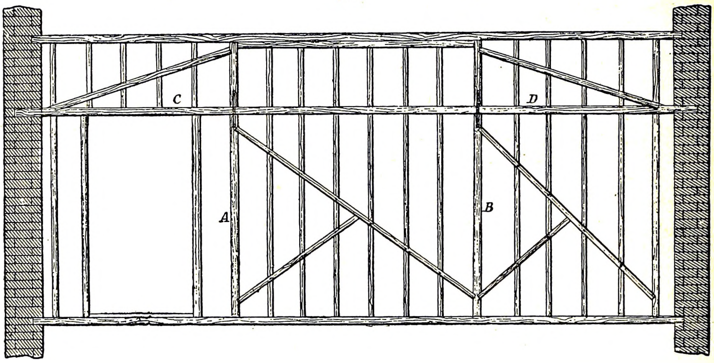
Ceiling joists need never be more than 2 in. in thickness, and the depth may be found by dividing the length in feet by the cube root of the breadth in inches, multiplying the quotient by 0·64 for fir, or by 0·67 for oak. Girders should never be laid over openings such as doors or windows, nor very obliquely across the rooms. As the span of the girder is increased, wall plates and templates should be made stronger. The following are the usual proportions;—

	in.		in.
For a 20 feet bearing, wall plates	4½	by	3
„ 30 „ „	6	„	4
„ 40 „ „	7½	„	5

Floors when first framed, should be kept about ¾ in. higher in the middle than at the sides of the room, to allow for settling.

In constructing floors with short timbers, several ingenious methods have been proposed; in Fig. 778 A, B, C, D, represent the plan of a room with four joists mortised and tenoned together at *a*, *b*, *c*, and *d*; each joist being supported at one end by the wall, and at the other by the middle of the next joist. Fig. 779 represents another method of constructing the floors with timbers shorter than will reach across the room. A very singular floor constructed on a large scale, for a room 60 ft. square, exists in Amsterdam, and this has no joists whatever; strong wall-plates are firmly secured on each side of the room, and rebated to receive the flooring. The flooring consists of three thicknesses of 1½-in. boards; the first thickness being laid diagonally, the ends resting in the rebates of the wall plates. The second series of boards is also laid diagonally, but in reverse direction. The third layer of boards are parallel to one of the sides of the room. All the boards are grooved and tongued together, and form a solid floor 4½ in. in thickness. The strength of plates supported in this manner is directly as the square of their thickness, and they will support a weight in the middle whatever the extent of bearing. With a uniformly distributed load, the strength is inversely as the area covered by the load.

780.



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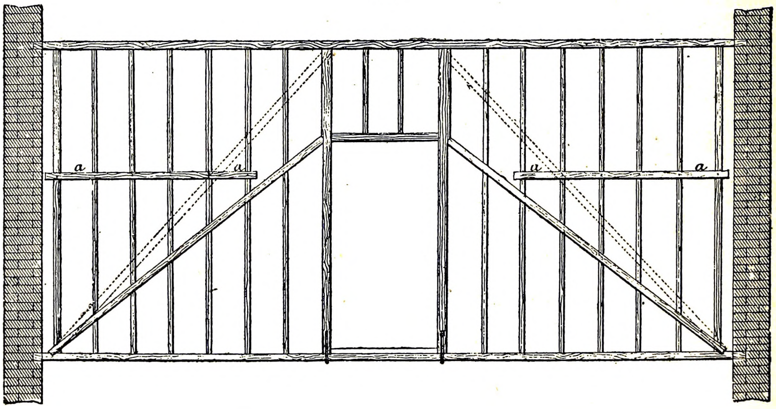


In carpentry, partitions are frames used for dividing the space of the house into rooms. Partitions are often of considerable weight, and therefore should have adequate support. They are frequently allowed to rest on the floor, and cause an unequal settlement. Partitions that cannot be supported by a direct bearing on the wall, should be strapped to the floor or the roof above, in preference to being laid on the floor below. The partition ought to support its own weight, and this may be attained by trussing over the heads of doorways. When partitions have a solid bearing throughout their length braces are unnecessary, and partitions may be stiffened by struts between the uprights. It is not, however, preferable to give a solid bearing to partitions throughout, as the settling of the walls would cause fractures, but the partition should be supported only by the wall to which it is connected, so that all may settle together. The following data will assist in forming an estimate of the pressure on the framing of partitions :—

		lb.		lb.	
The weight of a square of partitioning may be taken at ..	from	1480	to	2000	per square.
The weight of a square of single joisted flooring, without counter-flooring	„	1260	„	2000	„
The weight of a square of framed flooring, with counter-flooring	„	2500	„	4000	„

Fig. 781 is a trussed partition with a doorway in the middle, the tie, or sill, being intended to pass between the joisting under the flooring boards. Position of greater strength for the inclined pieces of the truss is shown, as the truss would have been weakened if, with the same quantity of material, these pieces had been placed as shown by the dotted lines. Trussed pieces should be inclined to the horizontal line, at an angle of about 40°. The horizontal pieces *a a* are notched into the uprights and nailed; with the doorway at one side of the room, the partition should be trussed over the door, as shown in Fig. 780. Posts A B are strapped to the truss, but in order to save straps are often halved to the inter-tie C D, which in that case should be made slightly deeper. Partitions should be put up some time before they are plastered, to allow for warping.

A centre, or centring, is the timber frame, or set of frames serving as a temporary support, and at the same time as a guide, placed under an arch during progress of construction. The centring must be of sufficient strength to sustain the arch stones without change of form, while the work proceeds. The centring is the template in wood of the entrados of the finished arch; and its essential parts are, in bridge work, the ribs which span the space between the piers; the bolsters or boarding, which lie transversely, and support the voussoirs; the keys, or striking plates, beneath the ribs, which are struck to lower the centring; and a sufficient amount of framing to hold the ribs and bolsters securely.

A cocket-centring is one in which head room is left beneath the arch above the springing line, upon which the temporary supports of the centring may have to rest.

Centring should be easily removed, and so designed that removal of part does not interfere with the supporting of the remainder. In navigable rivers, to allow for the passage of vessels, the centre must span the whole width of the archway, or be framed so as to leave a considerable portion unoccupied. In narrow rivers the framing may be erected on horizontal tie-beams, supported by piles, or by frames, fixed in the bed of the river. In large arches, the arch stones frequently force the centre out of form, and cause it to rise at the crown, unless the crown is proportionately loaded. Loading is, however, an imperfect remedy. Ribs of centres are usually 4 to 6 ft. apart, and are placed one under each of the external rings of arch stones, the space between being equally divided by the intermediate ribs. A bridge of three arches will require two centres; one of five arches, three centres.

The first point to be determined as regards the stiffness of centres, is the pressure at different periods of the formation of the arch. It has been found experimentally that the inclination of a plane must attain about 30°, before a stone placed upon it begins to slide, and it is not until sliding occurs that the arch stones press upon the centre. A hard stone laid upon a bed of mortar begins to slide at 30 to 40°, and a soft stone at about 45°, if it absorbs water sufficiently quickly to partially set the mortar. Pressure may be generally considered to commence at the joint which makes an angle of about 32° with the horizontal. This angle is termed the angle of repose, and if the pressure is represented by the radius, the tangent of this angle will measure the friction. When the pressure is unity, the friction will consequently be 0·625. The course of stones next above the angle of repose will press upon the centre, and the pressure will increase with each succeeding course. Hurst gives the following formula for determining the relation between the weight of an arch stone, and its pressure upon the centre, in a direction perpendicular to the curve of the centre—

$$W\,(\text{sin. } a - f \text{ cos. } a) = P\,;$$

where W is the weight of the arch stone, P = the pressure upon the centre, f = the friction, and a = the angle that the plane of the lower joint of the arch stone makes with the horizontal.

When the angle which the joint makes with the horizon is 34°, P = ·04 W, and at 36°, this co-efficient of W becomes ·08, at 38° = 0·12, at 40° = 0·17, at 42° = 0·21, at 44° = 0·25, at 46° = 0·29, at 48° = 0·33, at 50° = 0·37, at 52° = 0·40, at 54° = 0·44, at 56° = 0·48, at 58° = 0·52, at 60° = 0·54.

When the plane of the joint is so much inclined that the vertical line passing through the centre of gravity of the arch stone, falls without the lower bed of the stone, the whole of the weight of the arch stone may be considered to rest on the centre.

From these data the weight upon the centre can be easily estimated. For example, to determine the pressure of the arch stones, upon 20° of the centre, from the joint, which makes an angle of 32° with the horizontal; take from the given numbers the decimals relating to every second degree for the first 20°, and add them together. This sum, multiplied by the weight of a portion of the arch stones between 2°, will give a product which will be equal to the pressure of 20° of the arch upon the centre. In illustration, suppose the frames of the centre to be 5 ft. from middle to middle, and the depth of the arch stone to be 4 ft.; let the space between 2° of the arch measure, at the middle of the depth of the arch stone, 1½ ft. The solid contents will be 30 cubic ft.; and as the weight of a cubic foot of stone may be assumed to be 150 lb., the weight of 2° will be 30 × 150 = 4500 lb. Adding together the decimal fractions for 20°, that is, from 32° to 50°, the sum is 2·26. This sum multiplied by 4500 lb. gives 10,170 lb. for the pressure of 20° upon one rib of the centre. The pressure increases very gradually until the joint makes a large angle with the horizontal, and in designing centres the strength should be directed to the parts where the strain is concentrated. At the point where the joint makes an angle of 44° with the horizontal the arch stone exerts only one-quarter of its weight upon the centre, but near the crown the whole of its weight, so that to make the centre equally strong at each of these points would involve great waste in the application of the material. If the depth of the arch stone is double its thickness, its whole weight may be considered to rest upon the centre from where the joints make an angle of 60° with the horizontal. If the length is less than twice the thickness, the angle will be below 60°; if the length is greater than twice the thickness, the angle will be above 60°.

The error introduced by considering all arch stones with the joints above 60° as pressing wholly on the centre, is not a very great one, but it is frequently desirable, especially with circular arches, to attain a closer approximation. In any case, pressure, perpendicular to the curve of the centre, will be expressed by the equation previously given, but it is more convenient to measure the angle a from the vertical line passing through the crown, then the converse equation is—

$$\text{W}\,(\text{cos.}\ a - f\ \text{sin.}\ a) = \text{P}.$$

Denoting the angle included between the joints by a, the pressure of any number n of arch stones alike in weight and position, will be expressed by

$$\text{W}\left(\frac{\text{cos.}\ \frac{n}{2}\,a \times \text{sin.}\ \frac{n+1}{2}\,a - f\ \text{sin.}\ \frac{n}{2}\,a \times \text{sin.}\ \frac{n+1}{2}\,a}{\text{sin.}\ \frac{1}{2}\,a}\right) = \text{pressure} = \text{P}.$$

The arc a being ascertained, the sines and cosines to a radius of unity can be found from a table of natural sines; and the calculation simplified under the following form;—

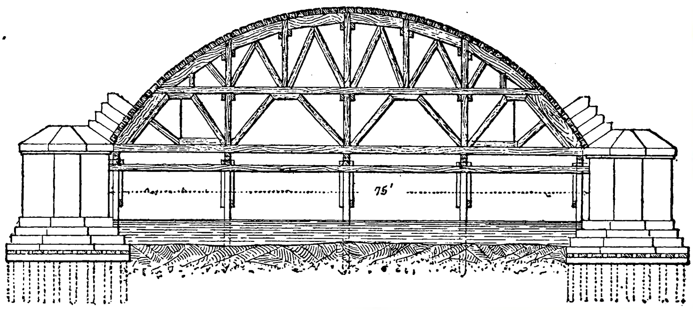
$$\frac{\text{W} \times \text{sin.}\ \frac{n+1}{2}\,a}{\text{sin.}\ \frac{1}{2}\,a} \times (\text{cos.}\ \tfrac{1}{2}\,n\,a - f\ \text{sin.}\ \tfrac{1}{2}\,n\,a).$$

With small arch stones the pressure upon the centre is greater than with large, weight for weight; when the arch stones are smaller than would be included in 1° of the arch, the error ceases to be in excess. The whole pressure upon the semicentre may be determined by the following equation;—

$$\text{W}\left(\frac{\text{cos.}\ \frac{n}{2}\,a \times \text{sin.}\ \frac{n+1}{2}\,a}{\text{sin.}\ \frac{1}{2}\,a} - \frac{f \times \text{sin.}\ \frac{n}{2}\,a \times \text{sin.}\ \frac{n+1}{2}\,a}{\text{sin.}\ \frac{1}{2}\,a}\right).$$

It is essential that the centre should be designed so as to support either a portion or the whole of the weight of the arch, without deformation. Fig. 782 is of Telford's design for a centre with intermediate supports, used for a bridge over the River Don, of which the span is 75 ft. Fig. 783 is for a stone bridge at Gloucester; the method of construction was as follows. A level platform was prepared, on which the centre was struck out to the full size. On the piles were laid tiers of beams lengthways to the centre, one under each rib, and upon these beams wedges were fixed, which were of three thicknesses, the bottom one being bolted down to the beams. The tongue or driving piece

782.



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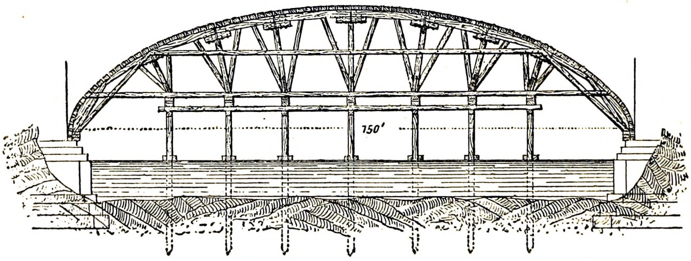
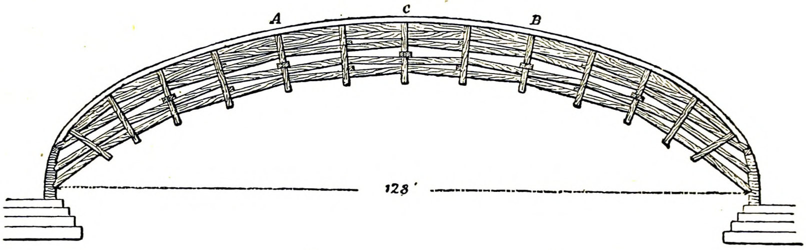


in the middle was of oak, hooped at the driving end. Each rib of the centre was put together on a scaffold made at the top of the wedge pieces, and was lifted by two barges on the river and two cranes on shore. The scaffold was extended 30 ft. beyond the striking end of the wedges to rest the last ribs upon previously to raising, and to give the workman position on which to operate. The ribs, when braced, were covered with 4-in. sheeting piles. The striking of this centre was effected in three hours, by placing beams upon the top of the work directly over the ends of the wedges and fixing to these beams a tackle carrying a ram of 12 cwt. to strike out the driving end of the tongue piece of the wedge; after the wedges were started, pieces were put in to prevent them going farther than was required. The coverings, or laggings, were then removed, and the ribs taken down in the order in which they were put up, and the piles drawn.

Fig. 784 is for a centre, designed by Peronet, for a bridge at Neuilly, where intermediate supports could not be obtained; in such case the construction of the centre includes the taking of precautions against the tendency of the crown to rise when the sides are loaded; for this purpose the design illustrated by this figure is defective, because when loaded at A and B, the centre must rise at C, and as the timbers approach the parallel the strains produced by the weight at any point must be greater than the joints can bear. Fig. 785 is for the centre of Waterloo Bridge, where this defect is avoided.

784.



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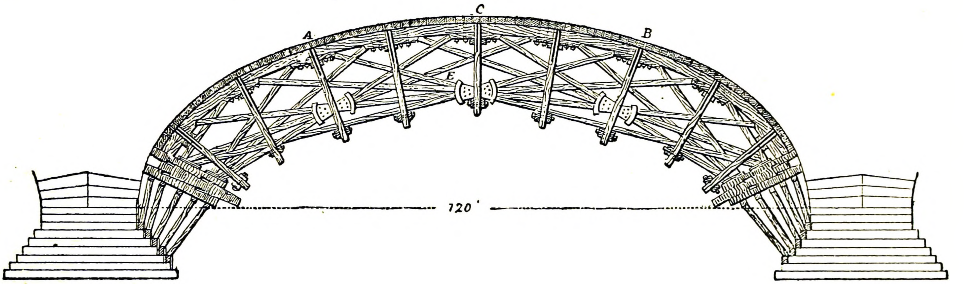
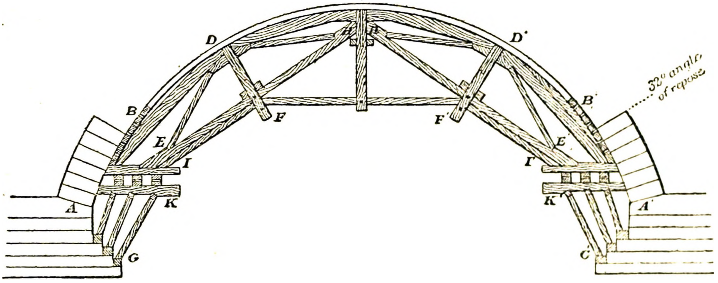


A load at A could not cause the centre to rise at C without reduction of the length of the beam A E and of the opposite beam. The design, however, provides an excess of strength, and is complicated. If the line A C A′, Fig. 786, be the curve of an arch, and the angle of pressure of the arch stones B′ B is 32°, and if the two trussed frames E D H, E′ D′ H′ abut against each other at C, the point C cannot rise from pressure at D D′ and by adding the piece F F′ as well as the pieces F I, F′ I′, great security is obtained. The curved ribs must be strong enough to sustain the weight between B D and D C. The bearings may be shortened by increasing the length of the abutments D D′. The beams E C, E′ C act as ties, and if the arch stones are laid beyond the points D D′ then they act as struts. This arrangement requires timbers of considerable length. If the built beams E F, F F′, and F′ E′, Fig. 787, be each trussed, and abut at F and F′, when the loads press equally at D D′, the beam F F′ will have no tendency to rise. The centre of this design may be applied to any span to

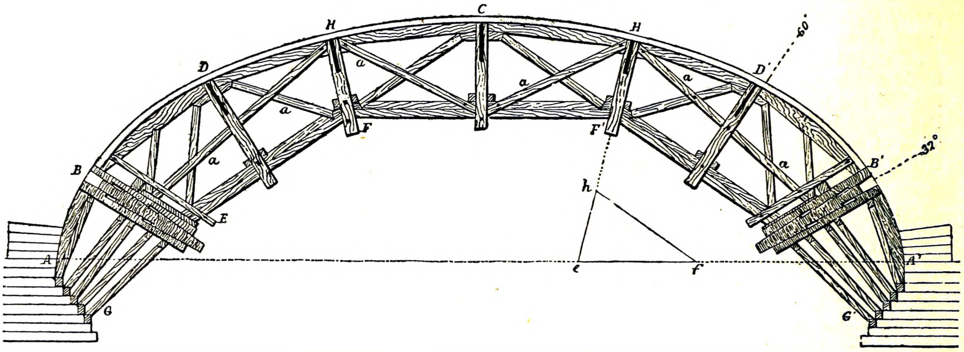
786.



which a stone bridge can be built. If timber of sufficient length is not available the beams **E F**, F F′, and F′ E′ may be built up.

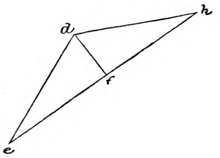
Fig. 788 is for a centre well adapted for tunnels, framed upon the principle of a queen-post truss. The backings of the rib are usually of two thicknesses of 3-in. plank bolted together, and the distance of the ribs about 5 ft. from each other. If raking struts are required during excavation, the leading ribs should be constructed without ties, as this would interfere with the struts.

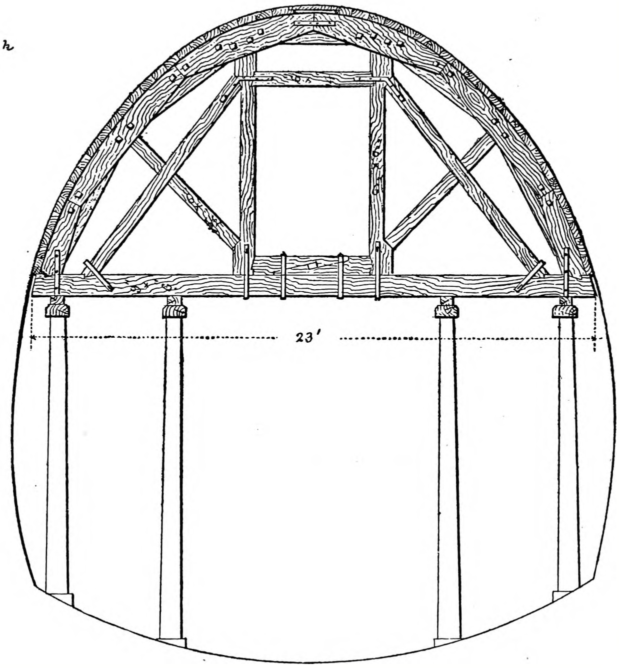
787.



788.

787*.





The principal beams of the centre should, where possible, be made to abut end to end, or to abut into a socket of cast iron. Intersection of timbers should be avoided, as it increases the number of joints. Pieces bearing towards the centre should be notched upon the framing, and be in pairs, one on each side of the frame, well bolted together. The braces marked *a a*, Fig. 787, are supposed to be so treated. Where many timbers meet, ties should be continued across the frames, and the ribs braced diagonally.

In order that centres may be easily removed, the principal supports should be placed upon double wedges, or upon blocks with wedge-shaped steps, so that these may be driven back to allow the centre to fall regularly. Centres should be removed gradually, in order to allow the arch to take equal settlement, and so that it may not acquire too great velocity. The wedges in small centres may be driven back with mauls, but in larger works a beam is used as a battering ram. The wedges should be marked before they are started, so that the distance to which they are driven may be easily measured and regulated. The centres should be slightly relieved as soon as the arch is completed, in order that the arch may settle before the mortar becomes hard. It is consequently necessary in striking centres, to be enabled to allow them to rest during any period of the operation. A novel method of striking centres was adopted at the bridge of Austerlitz, in Paris, in 1854, and subsequently for several bridges erected in India. Iron cylinders, 12 in. in diameter and height, were employed, open at both ends and placed vertically on a wooden platform.

This platform was the lower striking plate of the centre. The cylinders, to prevent them from slipping were placed on discs of wood, fastened to the platform and fitting the interior diameter of the cylinders, which were nearly filled with fine dry sand; on the top of the sand was fitted a wooden piston. The apparatus was then introduced under the centres instead of wedges; and by allowing the sand to flow gradually away, the centres were removed at the speed required. The centres of Waterloo Bridge were placed upon blocks, having wedge-shaped steps, Fig. 785. Again, in Fig. 786 the steps are supposed to be formed on beams, that reach across the whole width of the bridge, passing between the feet of the trussed frames and the supporting posts. By this method the centre may be removed without the necessity of placing workmen beneath.

Simple designs are best for centres, as it would be extremely difficult to obtain a sufficiently accurate estimate of the strength of a complicated centre. In the centre, Fig. 786, the stress tends to strain the frame E D H, also the pieces E H, H′ E′, when fully loaded, and the posts G K, G′ K′. To calculate the dimensions of the timbers required, let the pressure of the arch stone between B and C be determined, as previously described, and consider half this as weight collected at D, and acting in the direction D F. Then the strains in the direction of each of the beams of the frame E D H must be found. Ascertain the pressure of the arch between D and C, and consider it as acting at C vertically; the strain on the beams E H, H′ E′ can then be found. Finally, let the whole pressure of the arch stone between B and C with half the weight of the centre, be considered as acting at E vertically, and find the scantlings of the supports K G, K′ G′ that will resist this pressure. If the length in feet of any of the pieces be less than one and a quarter times the breadth, or smallest dimension, in inches, the joint will give before the timber will bend. When the length between the points of bracing is less than in this proportion, the scantling must be found by the following rule. The pressure upon the beam in pounds divided by 1000, gives the area of the piece in inches, or that of the least abutting joint, if that joint should not be equal to the section of the piece. This rule may almost always be applied for centres, because all long pieces may be secured against bending, by cross bracing, or by radial pieces being notched on and bolted to them. In Fig. 787 the beams E F, F F′, and F′ E′ are the chief supports. If the whole weight of the ring between D and C be considered to act in the direction H F at the joint F, it will be the greatest strain that can possibly be attained from the weight of the arch stone at that point. Produce the line H F to *f*, make *h f* equivalent to the pressure, draw *h e* parallel to the beam E F. As *h f* represents the pressure of the arch between D and C, *h e* will be the pressure in the direction of the beam F E, and *e f* the pressure in the direction of the beam F F′. Estimate the weight of the arch from H to H′, let two-thirds of this be considered to act as the weight at C vertically, and this will be the greatest load likely to occur at that point. The frame E D H may be calculated to resist half the pressure of the arch stones between B and H. The total weight of the arch stones from D to C, with the weight of the centre itself, may be considered as acting vertically at E, and the supports G E designed to resist this pressure. The scantling of that part of the rib between H and C, or D and H, may be calculated by considering the weight of this portion of the arch as uniformly distributed over the length.

Take for example the centre Fig. 786, which is designed for a stone arch of 50-ft. span; the stone weighs 130 lb. to the cub. ft., arch stones 3 ft. deep, and ribs 5 ft. from middle to middle; as the radius of the arch is 26 ft., the radius of an arc passing through the arch stones will be 27·5 ft.; the length of this arc for one degree equals its radius multiplied by ·01745329 = ·48. And 5 × 3 × ·48 = 7·2 ft., the solid content of one degree of the ring of arch stones. Referring to equation, page 299, W × 32·26 = 7·2 × 32·26 × 130 lb. = 30,195 lb. for the pressure of the ring between B and C; suppose this pressure to act in the direction D F, and to simplify matters, let it equal 31,000 lb.; draw *d f*, Fig. 787*, parallel to D F, set off *d f* equal 31 parts, and draw *c h* parallel to the beam E H; make *d e*, *d h* parallel to the principal rafters of the frame E D C. Measure *d h* by the same scale as *d f*, it will equal 70 parts, and as both the rafters make the same angle with straining force, the strain on each will be $\frac{70000}{1000} = 70$ in. for the area, of which each rafter will be about 8½ in. square. The strain in the direction E H need not be calculated, because when the tie-beam is strong enough to resist the other strains, its strength to resist tension will be more than enough.

Coffer-dams, Shoring, and Strutting.—The thickness of the dam, or distance between the outer and inner rows of piles, will depend on the depth of the water to be resisted, and to some extent on the stiffness of the soil through which the piles of the dam are to be driven.

The common rule for the thickness of a coffer-dam is to make it equal to the depth of water when such depth does not exceed 10 ft., and for greater depths to add to 10 ft. one-third of the excess of depth above 10 ft.

When the height of the dam above the surface of the ground exceeds 15 or 18 ft., three and sometimes four or more parallel rows of piles are driven, thus dividing the thickness of the dam into two or more equal divisions, each of 5 or 6 ft. thick.

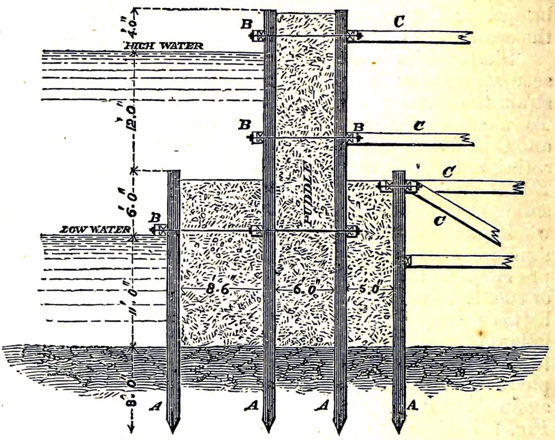
The height at which the dam should stand above high water will depend on the situation; the more exposed it is, the higher will the dam be required; in ordinary cases 3 ft. will be sufficient.

Before commencing a coffer-dam it is usual to dredge out all the loose soil on the site, which if allowed to remain would admit water under the puddle. Piles of whole timber, called guide piles, are then driven at intervals of about 10 ft. apart, to mark out the form of the dam; longitudinal timbers, formed of half-balks, called walings, are then bolted on each side of the guide piles, one pair near the top, and another pair at about the level of low water. These serve the purpose of keeping in their places the intermediate piles, which may now be driven.

Fig. 789 is a dam adapted for deep water. The piles A A are of whole timber, 12 in. square, and shod with iron weighing 15 lb. The walings B B were in the first instance of half-timbers, 12 × 6 in., and were placed on both sides of each of the guide piles, but when the intermediate piles are all driven these are removed, and single walings of the same scantling are fixed on the two middle and inner rows of piles, and one waling 12 in. square on the outer row; the top walings of the inner row being double. The rows of piles are tied together with iron bolts which pass through the piles and walings, and are secured with large nuts and washer plates.

All the piles used in a coffer-dam should be matched previous to their being driven, so that they may fit close together, and prevent leakage through the joints as much as possible.

789.



The length of the piles will depend on the nature of the soil and height of the dam. For a depth of water of 5 ft. on a soft silty bottom, 25 ft. in thickness, Hughes recommends that piles of 45 ft. long should be driven 8 or 10 ft. into the solid ground under the silt. For such a depth of water a double dam formed of three rows of piles would be required.

When the depth of water in a tidal river is 10 ft. at low water and 28 ft. at high water, on a bottom of loose gravel and sand 12 ft. thick, with clay underneath, the dam should have four rows of piles. The heads of those of the outer row should be driven down to within 1 ft. of low-water mark and 5 ft. into the clay, making a total length of 28 ft. The two middle and inner rows to be driven to the same depth into the clay, the former to stand 3 ft. above high water, making a total length of 48 ft., and the latter about 11 ft. above low-water mark, making the length of the piles 38 ft.

A double row of waling pieces should be placed all round the tops of the piles, and be connected by wrought-iron bolts 1¼ in. square.

Owing to the great pressure to which the sides are exposed in deep water, coffer-dams require to be strutted from the rear; this is usually effected by forming counterforts of piles at short intervals, according to the strength required. These piles should be tied together with walings and stiffened by struts, and the portion of the dam between the counterforts should be strengthened by horizontal struts from the ends of the counterforts. In dams enclosing a narrow space, as in those for the piers of bridges, the strutting might be effected from opposite sides, but they should be so arranged as to be easily removed and refixed, if required, as the work proceeds.

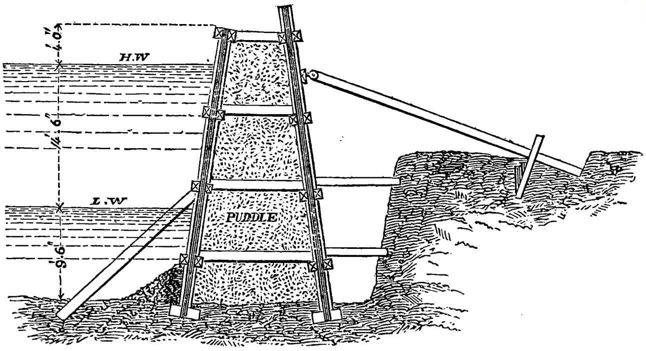
Struts in the body of the dam, at a level much below high water, are objectionable, as they would hinder the packing of the puddle and be a fruitful source of leakage afterwards, from the water creeping along them and causing the puddle to settle.

Iron bolts in the body of the dam, though also a source of leakage, are indispensable, in order to prevent the dam from bursting by the swelling of the puddle. These bolts should pass through the piles and be secured by nuts with iron plates, and large wood washers under both the heads and nuts, to prevent them working into the walings from the constant straining to which the dam is subject by the rise and fall of the tide.

In double dams these bolts are never allowed to go quite through from one side to the other, but if possible to break joint as it were in the body of the dam. The bolts in the lower part of the dam are shown to go through the outer and middle rows of piles only.

Fig. 790 is a form of dam used in extension of dock, which is well adapted for a half-tide dam, and was constructed inside a temporary barrier which had been erected to keep out the water while the site of a dock was being excavated. The thickness of the dam was 8 ft. at the top and about 16 ft. at the bottom, the total height being 28 ft. It was formed with guide piles of whole timbers at intervals of about 9 ft., to which the walings were bolted, and the intermediate spaces between the guide piles were filled in with sheeting piles, of half-timbers 12 in. by 6 in. The dam

790.



was designed so as to allow the timbers and vertical sheeting to be drawn, without running off the water from the dock, and the interior clay to be taken out by dredging. The piles and sheeting were secured to sills laid in chases cut in the rock, strutted to it at the bottom, and tied to it by iron rods, with split lewis bolts at the top; the former, with the view of removing it and the adjacent rock at a subsequent period, and the latter to guard against the pressure of the earth forcing the upper part of the dam towards the dock, before the admission of the water, and afterwards, if the water should by any necessity be reduced to a lower level than usual.

Wooden struts were used in the body of the dam, but they were arranged so as to interfere as little as possible with the packing of the puddle.

791.

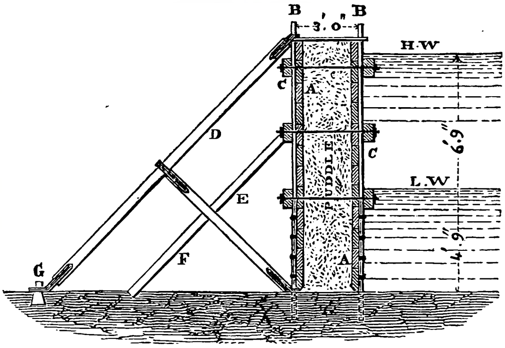


Fig. 791 is a simple arrangement for constructing a coffer-dam on rocky ground covered by water, for river works. It consists of two rows, 3 ft. apart, of planks, A, A, 3 in. thick, placed horizontally and held in their places by iron rods, B, B, $2\frac{1}{2}$ in. diameter, which are inserted in the rock at intervals of 3 ft. apart in each row. The two rows of rods and planking are tied together by transverse bolts passed through the body of the dam, and fixed to horizontal waling pieces C, C, 10 in. by 6 in., placed on the outside of the vertical rod.

The dam is strutted entirely on the inside by rows of strong struts, D, E, and F, placed 18 ft. apart. The outer stay D has iron eyes fixed at each end, to enable it to be dropped over the upper end of the vertical rod at the top of the dam, and over a pin inserted in the rock at the lower extremity G. A cottar at the upper end keeps the stay secure. The counter stay F is fixed at its lower end by the vertical rod of the dam, passing through an eye on the end of the stay, similar to that at G. The other end is strapped to the stay D.

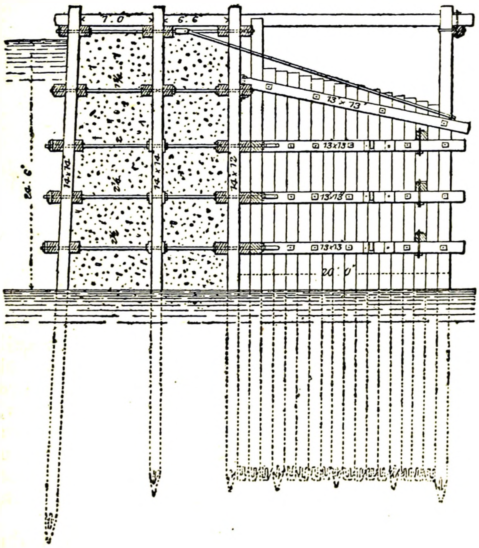
A sluice placed in the dam at the level of low water, enables the water to be let in should a sudden rise of the river endanger the stability of the dam. The space between the rows of planking is packed with puddle in the usual way.

In fixing the iron rods a jumper point is first worked at the end of each, they are then successively jumped into the bed of the river to depths varying from 12 in. to 18 in.; the planks of the lower tier are secured to the iron rods by clasps of iron, and slipped down into their places one above the other.

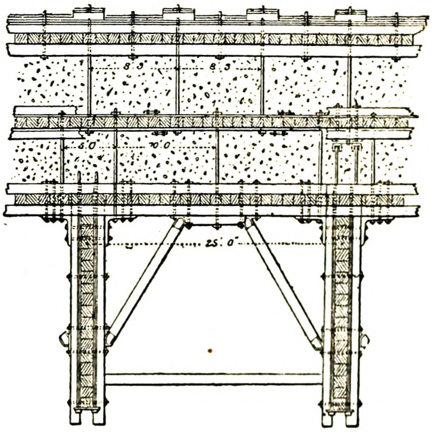
In removing the dam the puddle is first taken out, and the rods being moved to and fro, can be raised.

Figs. 792 and 793 are of a coffer-dam to resist a great head of water. Its length was about 1500 ft., 300 ft. of which were straight, and the remainder formed in two circular arcs of 150 and 800 ft. radii respectively, the convex side being towards the river. The depth at low water was from 4 to 10 ft., and the rise of the tide 24 ft. 6 in.

792.



793.



It consists of three rows of whole timber sheet piling, of Baltic yellow pine, from 13 in. to 15 in. square; the outside row battered half an inch a foot, and the other two rows upright. The sheeting is all driven between gauge or bay piles, placed 10 ft. apart. The three last piles driven in each bay are accurately sawn to a taper, in opposite directions, so as to wedge the remaining piles of the bay closely together. The average length of the piles in the first row is 55 ft., and in that of the other two rows 45 ft., though many of them exceeded 60 ft. in length.

The height of the piles above the ground is from 28 to 30 ft., all being driven down sufficiently far to enter a bed of hard clay. The width between the first two rows of piling is 7 ft., and that between the centre and back rows 6 ft. The front and back rows of piling were secured by five tiers of whole timber double walings; but in the centre row the three lowest tiers of waling are replaced by bands of wrought iron, keyed together in lengths of 12 ft., and forming a continuous tie on each side of the piling from the two extremities of the dam.

The transverse bolts are all break joint, never passing entirely through the dam, but terminating at the centre row of piling; they are screwed up against the wrought-iron plating, between which and the face of the pile is a washer of vulcanized indiarubber. These transverse bolts are $2\frac{1}{2}$ in. in diameter at the lowest tier of walings, diminishing upwards to $1\frac{3}{4}$ in., and in every bay of 25 ft., that is, between two counterforts, there were six through-bolts for each tier of walings, or thirty in each bay. The washer plates under the heads and nuts of the transverse bolts are of cast iron, 10 in. square, so as to give a large bearing surface on the timber.

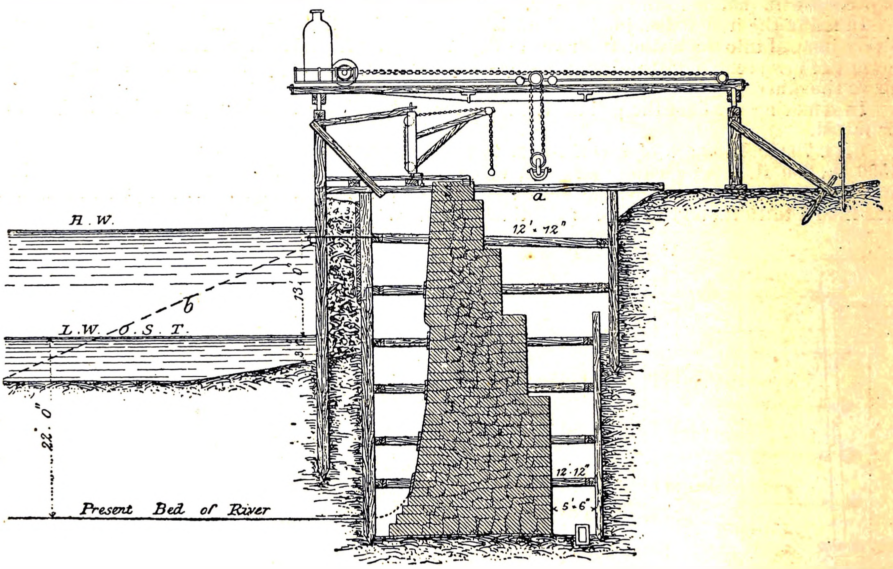
For the purpose of distributing the pressure, a cleat of hard wood, 5 or 6 ft. in length, is introduced between the walings and the washers, under all the bolt heads on the exterior face of the dam.

The dam is stayed at the back by counterforts placed at intervals of 25 ft. from centre to centre. These counterforts are 18 ft. in length from the back of the dam, and consist of close-driven rows of sheet piling of whole timber, strengthened by tiers of walings corresponding with those on the inner side of the dam, and connected with them by strong wrought-iron angle-plates, or knees, 6 ft. in length, through each of which one of the long transverse bolts of the dam passed. They were further strengthened by horizontal struts of whole timber, from 12 to 15 ft. in length, placed diagonally, and abutting in cast-iron dovetailed sockets 1 in. thick; of these struts there were three rows in the height of the dam.

The surface of the puddle in a coffer-dam should be covered with a layer of bricks, flags, or planking, to protect it from being injured or washed away. This will serve as a staging on which to deposit materials, or to lay rails for the purpose of carrying a traveller.

Coffer-dams should be provided with sluices, to let in the water in case of danger to the dam by the sudden rising of the water on the outside.

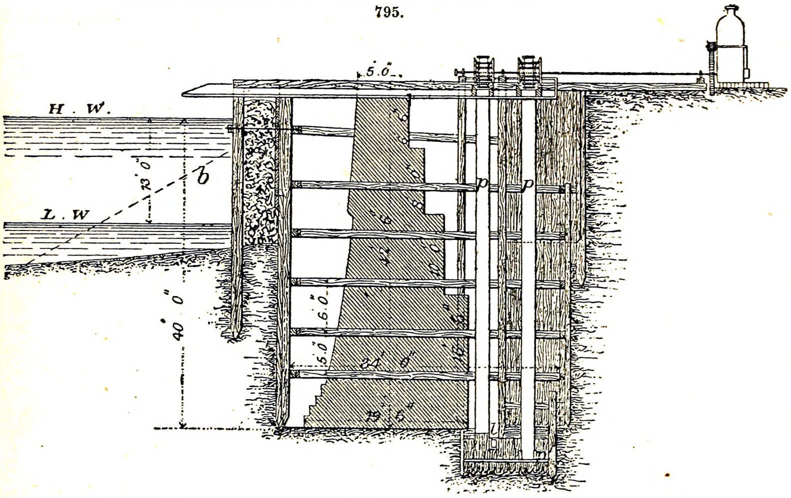
794.



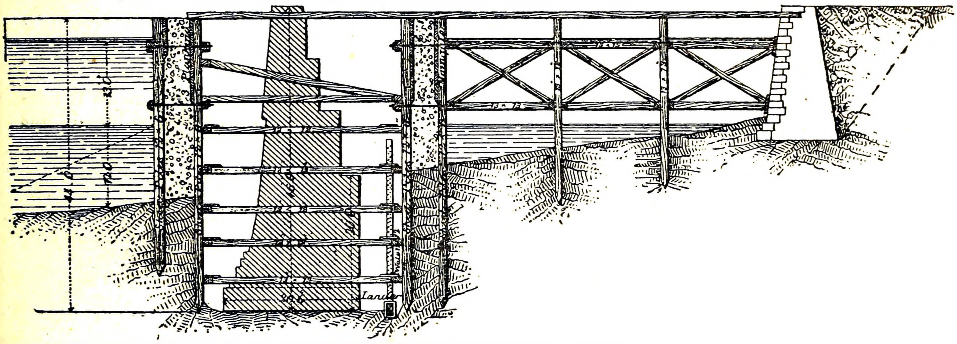
Figs. 794 to 798 are of a coffer-dam constructed by W. J. Doherty, for the erection of a river wall at Dublin, and described by him in the Minutes, Institute C.E. It consists of main piles of Memel timber, 32 ft. long by 12 in. square, driven as space piles on the outer row, 12 ft. apart from centre to centre, with corresponding main piles, 40 to 42 ft. long by 12 in. square, driven as an inner row, leaving a space of 4 ft. 6 in. between for the puddle. The space between the main piles of both rows was filled in with sheet piles, 12 in. wide by 6 in. thick; those on the outer row were driven 12 ft. into the ground, and reaching up to the water level, were 20 ft. long. Those on the inner row being of smaller length, were driven down to the level of the foundation of the new wall, 24 ft. below low water, their heads reaching 4 ft. above the water level.

The sheet piles on the inside of the dam were driven with their faces in a line with the main piles, so as to offer no obstruction to the settlement of the puddle, and the lower edge of the horizontal planking, 3 in. thick, with which the dam was sheeted on the inside, from the level of 3 ft. above low water to 3 ft. above high water, were levelled with the same object. Two $1\frac{1}{2}$-in. tie-rods of wrought iron were passed through two half-timber wales on the outside, and the inside of the main piles of the dam. They were provided with cast-iron washers on each end, 8 in. square and 2½ in. in thickness, screwed up with hexagonal nuts. The tie-rods were placed at 1 ft. above high-water level, and the other at 2 ft. above low water; these two tie-rods prevented the dam from spreading while the puddle was being tipped into place. Clay not being readily procurable, peat-moss was substituted and answered well, when thoroughly consolidated by pressure. The steam gantry necessary for the execution of the works was fitted on staging formed of uprights 9 ft. high and 12 in. square, resting on the heads of the main piles of the outer row; on these were placed longitudinal runners 12 ft. square, with similar uprights and runners on the land side, at a span of 50 ft., and braced with timbers, 12 in. wide by 6 in. deep. A row of continuous sheet piling, 26 ft. long, 12 in. wide, and 6 in. thick, was driven along the land side to support the adjacent roadway; it answered also to receive the strutting of the dam.

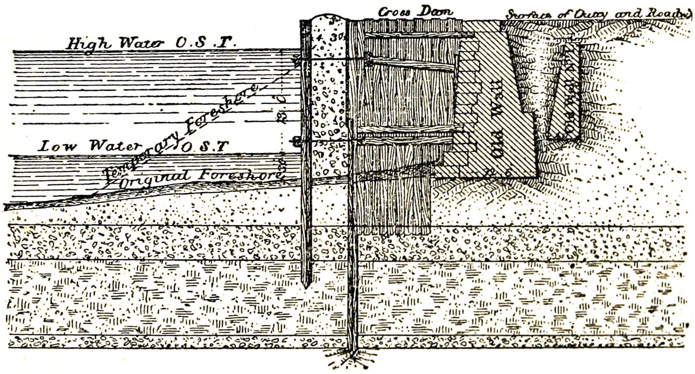
795.


5.0
H. W.
L. W
13'0"
b
p
p
40'0"
5.0
6.0
24'0"
19'6"

796.

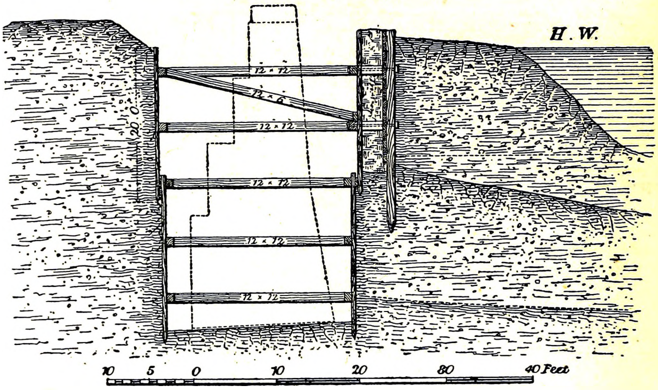

13'0"
44'6"
Lander

797.


Cross Dam
Surface of Quay and Roadway
High Water O.S.T.
Low Water O.S.T
Temporary Foreshore
Original Foreshore
Old Wall
Old Wall

As soon as about 200 ft. of wall had been built, a cross dam was constructed between the wall and the coffer-dam, by fitting a balk of timber against the wall opposite the main piles of the coffer-dam, and bolting to it at intervals of 5 ft. horizontal framing, into which close sheet piling was driven. Raking struts were carried from the whole timber against the wall and secured at the main piles of the dam at suitable distances. Clay puddle was tipped in behind the sheeting, and a row of short piles was driven in at the toe of the slope of the puddle to prevent it spreading. This enabled the coffer-dam to be drawn for the length thus cut off.

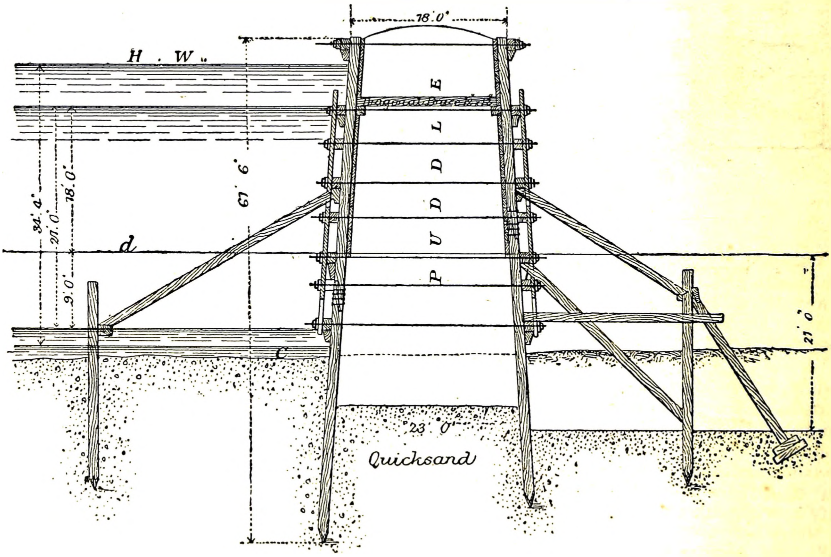
798.



To prevent the dam from being pressed outwards, a foreshore of dredged material was deposited on the outside up to low-water level, and piles and struts were placed from the inner dam landwards. Besides being in a great depth of water, it was found that the bed of gravel upon which the wall was founded, dipped considerably at this place; consequently the piling had to be driven to 28 ft. below low water, the depth at which sound gravel was met with.

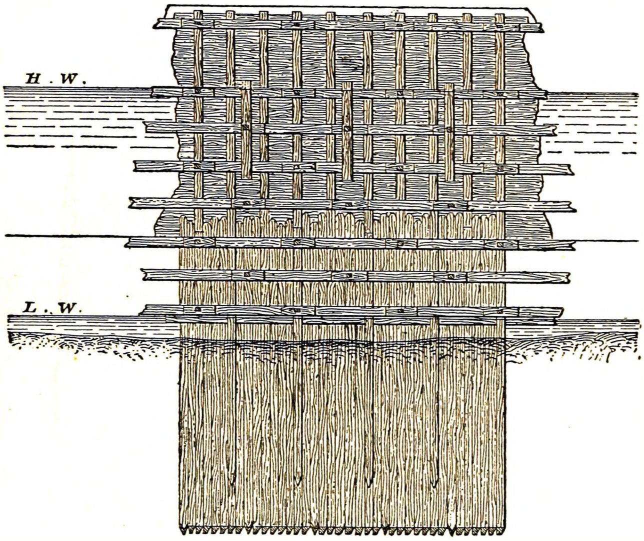
Figs. 799, 800, are of a coffer-dam across the entrance to the low-water basin, at Birkenhead, also constructed by Doherty. It was on plan the segment of a circle whose chord was 476 ft. and versed sine 76 ft. The width at the top of the dam was 18 ft., and at the ground line 23 ft.; its extreme height from the toe of the outer row of piles to the top of the dam was 61 ft. 6 in. It was formed with two rows of whole piles, inclined in either direction, the outer row in lengths of 35 to 40 ft. 12 in. wide by 14 in. thick, driven close as sheet piles, with toes reaching to 35 ft. below the old dock sill; the inner row driven also as sheet piles, with toes reaching to 30 ft. below the same datum. On every fourth pile of both rows was placed an upright 12 in. by 14 in. thick, by means of a scarf 4 ft. long, secured by four 1-in. bolts, reaching to the level of 3 ft. above high water, the whole being secured by five tiers of wales, placed on the outside of the piles and uprights at vertical distances of 8 ft. Through these wales were passed, at distances of 12 ft., a series of 2-in. wrought-iron tie-rods screwed at each end with hexagonal nuts on cast-iron washers, 9 in. square by 2 in. thick. At the level of high water of spring tides, an inner wale, 12 in. square, was bolted,

799.

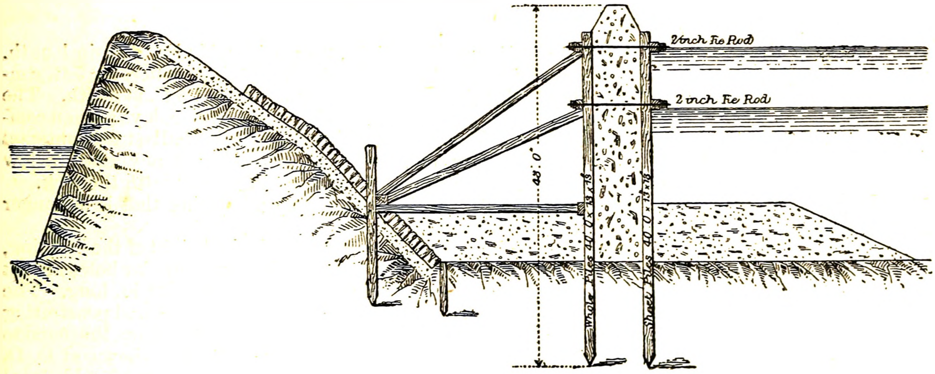


for the purpose of keeping the uprights asunder to the proper width at the top. The whole of the interior of the dam, on both the outer and inner row of uprights, from the level of the old dock sill to the top was sheeted with horizontal planking, 3 in. in thickness, to hold the puddle; the ground upon which the dam rested was chiefly of fine sand, which became quicksand when saturated with water; this dam was eventually destroyed by undermining and pressure from without, and was a costly failure.

800.



801.

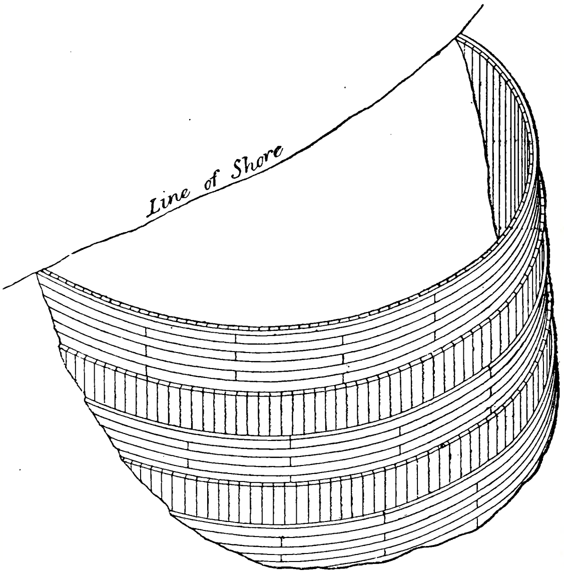


The dam, Fig. 801, was constructed to resist a constant instead of a tidal head of water, and is almost straight; it is 470 ft. long, and consists of two rows of whole piles, each 40 ft. long by 13 in. square, driven as close sheeting, about 10 ft. into the ground, and 6 ft. apart between the inner surfaces. It was braced together with two sets of wales, one at the level of high water, and the other at 6 ft. below high-water level. Through each a 2-in. tie-rod passes, and is screwed up on timber chocks and washers outside. The deposit of mud within the dam was cleared out, with a dredger, before filling it with puddle. In use, after the water had been lowered 6 ft., the dam showed signs of yielding, and shoring struts 14 in. square were placed against the walings and pitching of the slope. It will be observed that through-bolts are used here, but such a plan is disadvantageous, as the puddle cannot be made tight round them; it sinks and leaves spaces round the bolts, although well rammed, and dams with other intermediate bolts almost invariably leak. Instead of these bolts, buttress piles may be driven at intervals, to withstand the pressure of the puddle, which may then be reduced in thickness.

Many engineers consider that coffer-dams may be dispensed with in hydraulic foundations, and prefer dealing with them by other methods, such as are described in the article on Bridges at p. 197 of this Supplement.

Fig. 802 is a peculiar form of coffer-dam constructed by Law at Rio de Janeiro, at the entrance of the graving dock, where, as the shore was bare granite, the ordinary form of coffer-dam could not be erected; the site of the proposed entrance was enclosed by the timber shield, cut at the bottom to the shape of the rock against which it was placed. The shape was measured by constructing a temporary stage, similar in form to the shield; the vertical depth was then taken with a rod, at distances of 6 in. apart, and thus a series of ordinates were obtained, to correspond with the bottom of the shield. The shield was built on the same temporary stage in a horizontal position; the first layer of planks being placed close together on templets, formed the requisite curve, just in the same manner as the lagging of an ordinary centre. In the next layer the planks were bent round the circumference at right angles to the former, being secured at each intersection by a 5-in. spike; then succeeded another layer of planks parallel to the first, and similarly secured; then another parallel to the second, and so on, till the total thickness of 18 in. was obtained, consisting of six planks of the ordinary dimensions, 3 by 9 in. wide by 14 ft. in length. The number of thicknesses of plank was increased according to the depth in water, for 5 ft. consisting of only two thicknesses, another plank being added at each additional 5 ft. in depth. The shield was constructed in three weeks by ordinary carpenters, and caulked in two days; when completed it was lowered without difficulty into place, being loaded with sufficient ballast to counteract buoyancy. It bore against the rock at either side without struts or bracing of any kind; a few pine wedges were inserted on the inner side, where the shield was not in contact with the rock.

802.



Shoring and Strutting.—Fig. 803 is the usual method of shoring up a building that is in danger of giving way.

A plank of timber 9 in. wide and 3 in. thick, the lengths varying with the height of the building, is placed against the upper part of the wall to be supported. In this plank rectangular holes are cut to admit of pieces of timber, called needles, from 4½ in. to 6 in. square, and about 12 in. long. The needles are passed through the plank, leaving about 4½ in. projecting on the outside, and penetrating about the same distance into the wall to prevent the planks from slipping, and on the outside to serve as an abutment for the ends of the struts A, A. These needles are shown at D, D, Fig. 803. A cleat E is usually spiked to the plank on the upper side of each needle for additional strength.

The struts A, A, called shores, are from 6½ in. for very small buildings, to 12¾ in. for large buildings; half-balks of timber, or about 12½ in., is a usual size. They are fixed at the lower end on a footing block F buried in the ground, and at the upper end against the under side of the needles D, D. The outer strut is called the top raker, and the inner one the bottom shore, the other being called the middle raker.

To retain the struts in their places, pieces of timber, B, about 1 in. thick and from 6 in. to 9 in. wide, are usually nailed on each side of the struts at a short distance from, or immediately under, the points where the needles enter the plank. In furtherance of the same object pieces of hoop-iron are nailed around the lower ends of the struts.

Sometimes, to save length, the top raker, instead of resting directly on the footing block F, is made to spring from the back of the strut immediately under it at a distance of a few feet from the ground, a large cleat being spiked to the back of the strut to assist in supporting it, or a piece of timber is continued to the footing block for the same purpose.

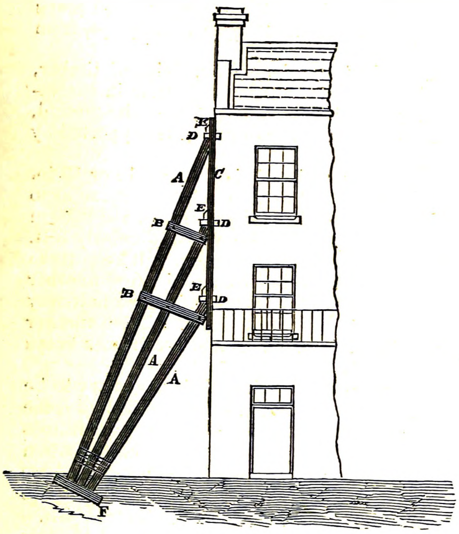
In cases of houses where one in a row or terrace is taken down, and the party walls of those adjoining are not sufficiently strong to stand without support, struts are placed between the houses on the opposite sides of the opening, in Fig. 804, D being a plank 9 in. wide and 3 in. thick, similar to that last described, Fig. 803, one of which is placed against each wall. Raking struts B, B are fixed to the upper and lower ends of the plank against the wall, and to the horizontal strut A, which they stiffen. The cleats E, E, and the straining piece C, are for the purpose of keeping these raking struts in their places.

The horizontal strut A may be from 6 in. by 4 in. to 9 in. by 6 in., and the raking struts B, B about 6 in. by 4 in., depending upon the height and distance apart of the buildings.

It frequently happens that the upper portion of the wall of a building has to be supported, while the lower portion is being removed, either wholly or partially, for the purpose of renewing the foundation, forming a doorway, or shop-front.

The method of shoring employed in such cases, though requiring extreme care on the part of the workmen, is very simple in principle. It consists merely in breaking one or more small openings through the wall, and inserting a beam or balk of timber in each of sufficient scantling to carry the wall above, and projecting at right angles on each side of the wall to admit of a stout prop being placed under each end. The props are made to rest on wedges so that the beam may be wedged up tightly against the wall which it supports. The wedges are placed on stout foot-blocks of wood or stone solidly bedded in the ground. If the alterations be extensive, and are likely to be attended with risk, struts as in Fig. 803 should also be applied to the building where required.

803.



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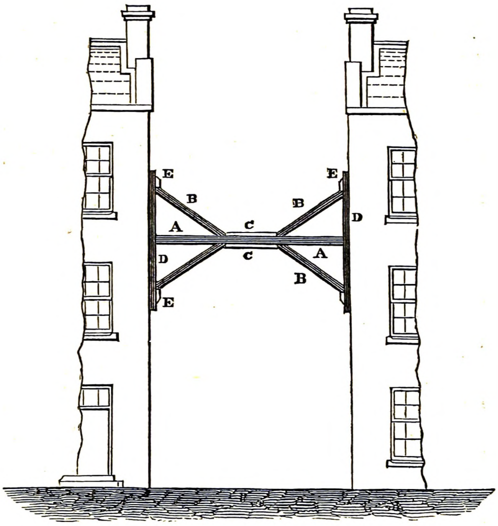
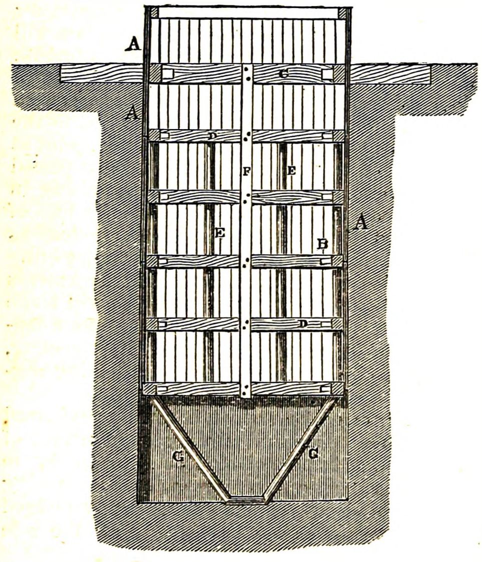


Shafts for tunnels, mines, or other purposes, when sunk through soft or loose strata, require to be lined to prevent the soil from being disturbed or the sides from being forced in. A shaft is said to be timbered when it is lined with wood. Brick-lined shafts are always circular on plan, but timbered shafts are usually made rectangular, and they vary in size according to the purpose for which they are intended. Four feet square gives the smallest area that men can conveniently work in. A shaft of this size is sometimes used for wells, trials, or ventilation; 6 ft. by 4 ft. is, however, a usual and more convenient size. Winding or working shafts require to be larger; 6 ft. by 9 ft. to 10 ft. square is a usual size for them, and they are sometimes made larger, particularly when they are to be used for the purpose of ventilation as well, in which case they are divided into upcast and downcast compartments by air-tight divisions called brattices.

805.



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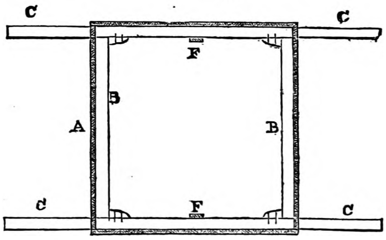


The lining, or cleading, of a shaft consists of boards, as A, Figs. 805 and 806, from 6 in. to 9 in. wide, which are placed against the sides and retained in their places by horizontal frames of timber B, B, called settings.

The distance apart of these frames is regulated by the nature of the ground passed through, and their scantling will depend on the size of the shaft and on the nature of the ground. Very soft ground requires stronger frames than merely loose or friable ground, which does not exert so much pressure against the sides of the shaft. Three feet is the least distance apart the frames are likely to be required even in the worst soils, but it should never exceed 6 ft.

For very small shafts in average ground the scantling of the frames should not be less than 4 in. square. In large shafts, 7, 8, and 9 in. are usual sizes. Cleats are used to keep the sides of the frame together, as by Figs. 805, 806. The thickness of the cleading A depends on the distance apart at which the frames are set; when they are about 3 ft. apart, 1 to 1½ in. is a usual thickness, and when about 6 ft. the cleading requires to be 3 in. thick. The former is, however, the safest to adopt in treacherous ground. The frames are kept apart at the regulated distance by vertical props E, E, Fig. 805, varying, according to the weight to be supported, and the length of the props, from 4 to 6 in. in diameter.

To prevent the tendency which the timbering has to slide down the shafts, strips of timber, F, F, Figs. 805 and 806, called stringers, are spiked to all the frames from top to bottom in succession, and the whole secured to two balks of timber, C, C, Fig. 806, laid on the surface of the ground, one on each side of the shaft. During the sinking of the shaft the last frame put in is supported by raking props, as G, G, Fig. 805.

In timbering a shaft 10 ft. square for a coal mine, two strong balks of timber, say 12 or 13 in. square, are laid upon the site of the shaft. The ground is then dug out to the depth of 3 ft., so as to allow the next frame to be laid. The inch deals, 6 ft. long, are set up behind the frame, the bottom ends of the deals passing down half its thickness, and these deals will rise perpendicularly 3 ft. above the surface of the ground, when a light frame, placed within them at the top, will keep them in their places. Six feet more in depth of ground is taken out and another frame laid, and another 6 ft. length of deals put in, also descending half-way down this third frame, and of course half-way up the second frame put in, and meeting the bottom of the first length of deals. Then another frame is placed midway between these, and a row of props placed between each set of frames keeps them all level and in their proper places.

When this has proceeded some depth, and the ground for a still further length is necessary to be taken out, there becomes a tendency for this timbering to slide down, and the balks first laid come into use. Planks, called stringing planks, are then spiked to these balks, and also to all the frames from top to bottom, thus hanging the whole. This may advantageously be done with chains when the whole pressure is downwards. Sometimes, however, it is upwards, although in all cases where this either occurs, or is in the least expected to occur, circular timber is almost indispensable. The reason why 3 ft. in the first length rises above the surface, is to allow of tip room for the rubbish.

The internal diameter of the circular cribs for an 8-ft. finished pit should be 9 ft., and the size of the timber in the cribs being, say 6 in. square, would allow about an extra foot all round for the walling, with which permanent shafts are frequently lined, the timber being taken out as the masonry is put in.

The mode of putting in these cribs is the same as that of the square frames. An accurate floor of wood is prepared, 11 ft. in diameter, in the centre of which is fixed a pivot, on which a radius of 6 ft. moves freely, and at 4½ ft. from the pivot is fixed an iron point, the use of which is to describe upon the floor a circle 9 ft. in diameter. At short intervals upon this circle spikes are driven in, leaving an inch of their upper part projecting upwards. The object of this is to form a rest to the inside of the segments during the operation of forming their joints.

The timber from which the cribs are to be cut is sawn into planking 6 in. in thickness, and then by means of a template set to the circle of the shaft or pit, each plank is as economically as possible cut out into as many segments as it will yield. Although it is evident that the inside of the ring, by being the segment of a circle of 9 ft. in diameter, will not correspond with the outside, which is that of a circle 10 ft. in diameter, yet it is sufficiently near, and thus the same cut that serves for the inside of each segment serves for the outside of another one, or in fact, the same template will make all the segments. Several segments having been sawn out in lengths varying from 2 to 4 ft., one of them is laid upon the floor, with its inner side resting against the nails inserted as above mentioned, and being pressed close to them two or three other nails are driven into the floor, on its outside, so as to keep the piece of wood firmly in its place. The radius rod is then applied to the piece, and as large a segment marked out of it with the point of a nail as will leave a 6-in. joint at each end. The end pieces are then sawn off. Another piece of wood is similarly treated and placed end to end with the first; then a third, and so on until the circle is completed. Before putting in the last or closing piece, however, it is better to pass a saw through each joint in the line of the radius of the circle, so as to make them more true, and to drive up the pieces as close as possible. Well curbs, somewhat similar to these cribs, are described at p. 200 of this Supplement.

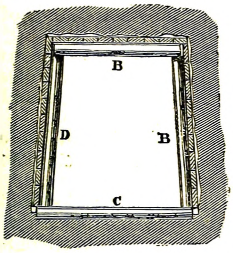
Each circle of cribbing may be sent down the pit in three parts, so many of the short segments as are necessary being nailed together, by means of top and bottom cleats of inch-deal, as will make a segment of about one-third the size of the crib. Each of these thirds to have at one end a top-cleat, and at the other end a bottom-cleat, nailed one-half upon it, and the other half projecting, with the nail holes already bored in them so as to allow of their being nailed to the adjoining segment without any delay.

Figs. 807 and 808 show one method of timbering a heading or gallery, which is usually performed with rough timber. Sole pieces C, C, from 4½ to 6 in. in diameter, are laid on the ground or floor of the heading. Short pieces of rough boards A, A, called poling boards, about 1 or 1½ in. thick, are placed against the roof of the heading, underneath which, so as to take the ends of the poling boards, balks of timber B, B, of the same diameter as the sole pieces, are placed and firmly wedged up by the props D, D. To prevent the props from being knocked away or slipping off the sole pieces, spikes, called brobs, are driven into the sole pieces around the ends of the props.

When the sides of the heading are likely to fall in, poling boards, Fig. 807, similar to those on the top, are fixed against the sides.

Fig. 809 is the method usually adopted for timbering the sides of trenches and narrow excavations. Poling boards A, A, about 3 ft. in length, 1 to 1½ in. thick, and from 7 to 9 in. wide, are placed against the sides of the excavation as each successive depth of 3 ft. is excavated. An ordinary deal plank B, 3 in. thick and 9 in. wide, called a waling, is placed longitudinally against the middle of each row of poling boards. The planks on opposite sides of the trench are kept in their places by struts C, C, laid across and tightly wedged against them. The struts vary in size from 4 in. square to 6 or 8 in. square, according to their length and the pressure they have to sustain. This mode of timbering can be executed as the work proceeds, and the timbers can be readily taken out in parts when required.

807.



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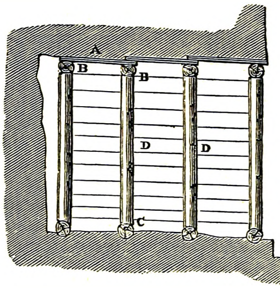

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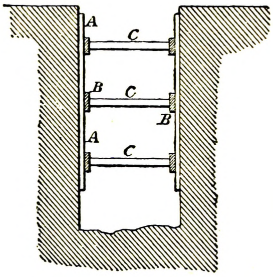


When the soil is so loose that the sides of the excavation cannot be upheld until a sufficient depth is dug to admit of the insertion of the 3-ft. poling boards, long planks called runners, usually of deal 3 in. thick and 7 or 9 in. wide, pointed and sometimes shod with iron at one end, are placed behind the walings instead of the poling boards. The walings in this case require to be of stout timber, frequently as much as 12 in. by 6 in., and the struts should be proportionally strong. The runners should be constantly driven as the work proceeds, and their points kept about 12 or 18 in. in the ground below the bottom of the trench, to prevent the sides from falling in and to permit the excavation to be carried to the required depth. These runners are, however, difficult to draw out afterwards, and they have sometimes to be left in.

CAST IRON.

Cast iron is a granular and crystalline compound of iron and carbon, more or less mixed with uncombined carbon in the form of graphite, but never containing more than 5 per cent. It is harder than pure iron, more brittle, and not so tough, and is obtained by the direct reduction of iron ores in the blast furnace. The modes of combination of the carbon with the metal, as well as the nature and proportion of foreign matters, such as silicon, alumina, sulphur, phosphorus, and manganese, determine the infinitely varying qualities relating to its colour, degree of fusibility, hardness, tenacity, and so on.

Pig iron is the form in which cast iron appears when delivered from the smelter, consisting of rough oblong blocks of the metal, which have been run direct from the smelting furnace into open moulds.

In practice, the different varieties of cast iron when in the pig, that is, as they are sent from the smelting furnace, are distinguished by the colour and general appearance shown by newly broken surfaces; these exhibit every variation from dark grey to dead hard white.

All cast irons are not available for foundry purposes; those preferred are irons which become sufficiently fluid upon fusion to fill every part of the moulds into which they are poured, which shrink but slightly upon cooling, which, once in a solid state, admit of easy manipulation, and whilst satisfying these conditions, possess sufficient strength for the purpose to which they are to be applied. These different qualities are found combined in a higher degree in grey cast iron than in white irons, and the former are therefore most generally used for foundry work.

Grey iron merges into white iron by imperceptible degrees, and in some irons the two are clearly developed in the fracture of one and the same pig; it is then called mottled iron, and this is frequently of great strength. Some seven or eight classes may be found running from clear white at the one extreme to dense grey at the other, and each class is commercially recognized by a distinctive number, No. 8 being the whitest, 5 the mottled, and the lower numbers including the grey varieties. But three kinds were at one time classified. In recent years, however, the larger number given above has been almost invariably adopted.

In white cast iron the greater part of the carbon is present in the form of a chemical combination, carbide of iron, whilst in grey cast iron the carbon is mechanically interspersed in small black cks amongst the lighter coloured particles of metal, the fracture being of a dark grey colour, and being of a granular or scaly crystalline character. Grey cast iron is much softer and tougher than white iron, and may be filed, or turned; whilst white iron is very brittle, and can neither be turned in a lathe nor filed.

These qualities may be altered to a certain extent, as by casting grey iron in thick iron moulds, or chills, it becomes almost as hard as steel; but this change takes place only at the surface, the inside of the casting still retaining its grey colour. If it is desired to soften a casting which is too hard to be turned or bored, this can be done by heating the casting for several hours in a mixture of bone-ash and coal-dust, or in common sand, and allowing it to cool slowly whilst still imbedded in these bad heat-conducting materials.

Grey cast iron requires a higher degree of heat before it commences to fuse, but becomes very liquid at a sufficiently high temperature, so as easily to be run into moulds.

White cast iron is not so well adapted for casting, as it does not flow well; it is rather pasty in consistence and scintillates as it flows from the furnace to a much greater extent than grey iron.

White cast iron is silvery white, either granular or crystalline, difficult to melt, brittle, and excessively hard.

This quality of iron is obtained by using a low temperature and a small quantity of fuel in the blast furnace. It is a homogeneous chemical compound of iron with from 2 to 4 per cent. of carbon, and is well suited for forge purposes, to which it is generally applied.

Granular cast iron can be converted into grey cast iron by fusion and slowly cooling; whilst grey cast iron can be converted into granular white cast iron by fusion and suddenly cooling.

Crystalline white cast iron is harder and more brittle than the granular, and is not capable of being converted into grey cast iron. This variety is too brittle for use in machinery.

The general composition of the three principal varieties of cast iron is shown by the columns marked F G H in the following table; while in column A is indicated that of the South Wales cinder pig; B, common white pig from the same locality; C, mottled iron made with charcoal and cold blast; D, Dowlais No 3 best mine pig; and E, Cleveland No. 2 foundry pig.

Grey cast iron contains about 1 per cent. or less of carbon in chemical combination with the iron, and from 1 to 4 per cent. of carbon in the state of graphite in mechanical mixture. The larger the proportion of graphite, the weaker and more pliable is the iron.

No. 1 contains the largest proportion of graphite; it is distinguished in appearance by great smoothness on the surface of the pig, and is the most easily fusible, produces the finest and most accurate castings, but is deficient in hardness and strength, in which it is inferior to Nos. 2 and 3.

It is indeed charged with carbon to excess, and when turned, free carbon may be observed flying off like powder. The crystals are large, extending over the entire fractured surface, which shows a characteristic blue-grey colour and coarse grain. When broken, the pig does not ring, but falls asunder with a dull leaden sound, and it usually breaks very evenly, showing but little tenacity. When fluid it is marked by a notable absence of either sparks or splashes. The surface is dark and sluggish, and as it cools it becomes covered with a thick scum, which is a source of much waste. Used very hot, as when melted in a crucible and air furnace, it is so fluid that it will run into the finest and most delicate moulds. This property, as already remarked, peculiarly adapts No. 1 foundry pig for the purpose of small thin and ornamental castings, and anything that requires a minute adaptation of the metal to the mould. No. 1 is not often employed by itself, but commonly as an admixture with scrap.

Table I.—Composition of Cast Iron. Spretson.

	A Grey Cinder Pig.	B Common White Pig.	C Mottled Iron.	D Best Mine Pig.	E Foundry Pig.	F Grey.	G Mottled	H White.
Iron	93·55	97·27	93·29	94·56	93·53	90·24	89·39	89·86
Combined carbon ..	2·80	2·42	2·78	0·04	..	1·82	1·79	2·46
Graphite			1·99	3·10	3·44	2·64	1·11	0·87
Silicon	1·85	0·36	0·71	2·16	1·13	3·06	2·17	1·12
Sulphur	0·14	0·87	trace	0·11	0·03	1·14	1·48	2·52
Phosphorus	1·66	1·08	1·23	0·63	1·24	0·93	1·17	0·91
Manganese	..	..	..	0·50	0·43	0·83	0·60	2·72

No. 2, which is lighter in shade than No. 1, is finer in grain, not so soft, it is not so fluid when melted, nor the skin of the pig so smooth. Being closer grained and more regular in the fracture, it is more tenacious, and while capable of being easily turned and polished, being harder and stronger than No. 1, it is preferred for strong ornamental castings. Melted, it is seen to be of a clear reddish white colour, splashing little when poured into the ladle. There is a scum and a sluggish flow, but not to the same extent as with No. 1. When being run into the mould, it breaks over the edge of the ladle in large sheets, leaving behind them long narrow lines running from side to side. As the iron cools, these lines open in various directions until the surface is in lively motion, lines intersecting each other in every direction. This activity continues until the surface becomes stiff or pasty, but on removing this covering, these lines are again seen flitting over the surface.

No. 3 is the most extensively used foundry iron, owing to its being a medium between the extremes, which can therefore be used for a variety of purposes. It has less carbon than the other two kinds, and possesses less fluidity when melted; it is also more minutely grained, and smoother in the fracture than No. 2. The broken surface shows a slightly mottled appearance at the margin, while at the centre there is a regular arrangement of smaller crystals comparatively compact and dense. As it flows into the ladles there is a display of sparks flying in various directions, and an absence of scum, the surface being clean. Figures are slightly visible at surface, but are small, and pass off entirely as the metal cools. It possesses a greater degree of toughness, as well as hardness, and turns out strong, durable castings; it is therefore selected for parts liable to great and sudden strains, and exposed to constant wear and tear; tram plates, for example, heavy shafts, wheels, and ordinary steam cylinders, where large quantities of scrap are available. It is the opinion of many founders that a considerable advantage can be gained by a liberal use of No. 3, in conjunction with a smaller mixture of good soft pig iron.

No. 4 foundry iron, as it is called, when fractured, is more or less mottled, with a whitish glossy appearance. The pig is difficult to break, and the fracture uneven, indicating a considerable amount of tenacity. When melted very hot it has a clean, glowing surface, and as it is poured it throws out showers of sparks in all directions, which continue to break into small particles, and fuse during their flight. This phenomenon is peculiar to this description of iron, but may be observed with other irons which have been very much exposed and oxidized by the atmosphere. While still in a melted state a constant succession of small globules rise to the surface, these expanding gradually and seeming to merge by degrees into the molten mass, being replaced continually while the iron remains fluid. On cooling, the surface is found covered by thin scales of oxide. No. 4 will be found applicable to very heavy castings, such as girders, bed-plates, engine beams, plain columns, and the like, especially where there is little after machine manipulation necessary. It is obviously ill adapted for light casting, as its density renders it useless for filling delicate moulds. The purely white irons are entirely unsuitable for foundry purposes, and are therefore beyond our consideration here.

The following remarks upon some points which we have already treated of may aid in roughly estimating the quality of a cast iron.

When the colour is a uniform dark grey, the iron is tough, provided there be also high metallic lustre; but if there be no metallic lustre the iron will be more easily crumbled than in the former case. The weakest sort of cast iron is where the fracture is of a dark colour, mottled, and without lustre.

The iron may be accounted hard, tenacious, and stiff when the colour of the fracture is lightish grey, with a high metallic lustre.

When the colour is light grey, without metallic lustre, the iron is hard and brittle.

When the colour is dull white, the iron is still more hard and brittle than in the last case.

When the fracture is greyish white, interspersed with small radiating crystals, the iron is of the extreme degree of hardness and brittleness.

When cast iron is dissolved in chloride of lime, or chloride of magnesia, the sp. gr. is reduced to 2·155; most of the iron is removed, and the remainder consists of graphite with the impurities of cast iron. A similar change takes place when weaver's paste is applied to iron cylinders. Sea-water, when applied for a considerable time, has the same effect. It takes much longer to saturate white cast iron than to affect grey. The soft grey iron yields easily to the file after the outer crust has been removed, and in a cold state is slightly malleable.

We may state also that the quality of iron in a melted state is readily judged of by a practised eye from the nature of the agitated aspect of its surface. The mass of fluid seems to undergo a circulation within itself, having the appearance of ever-varying network. When this network is minutely subdivided, it indicates soft iron. If, on the contrary, the iron is thrown up in large convolutions, the quality of the metal must be hard.

There are many individual exceptions to the ordinary classification of pig iron, which, although a matter of great convenience, is so far artificial, inasmuch as iron varies in quality, measured by the minuteness of the grain and foreign admixtures, by minute graduations between the two extremes. Considerable latitude is therefore allowed in the classification of pig iron.

"Scrap" or the broken-up fragments of every conceivable article which cast iron is employed to make, is as variable in composition as can well be imagined. A general characteristic is that it can be melted with less fuel, as it is deficient in the thick siliceous skin which usually covers the pig, and more can be melted in a given time, as the silica necessitates a liberal use of limestone or some other flux, by which course damage frequently occurs to the lining of the cupola. It should be observed that "scrap" has become altered from its original composition as often as it has been remelted, for on every cooling the parts nearest the surface become white and hard, that is, to some extent chilled, and containing, therefore, more combined carbon than before, and hence its common daily use as an addition to soft pig, in order to confer upon the latter greater hardness and closer grain. It is a mistake, however, to suppose that a casting made with fine-grained scrap will have a finer grain than that of the pig employed to make it, for it is obvious from a slight consideration of the laws of crystallization, alluded to at p. 313, that the fineness of the grain, that is, of the crystals in a finished casting, materially depends upon the size and the rate at which it cools.

It may not be out of place here to refer to the erroneous idea that repeated meltings improve the quality of cast iron; in fact, with many cases it is quite the reverse. Sir William Fairbairn gave this fallacy to the world some years since, and going forth as it did under the sanction of his name and justly regarded reputation, it has been repeatedly received as an established fact. To that great master of the founders' art, Robert Mallet, is due the disproval of Fairbairn's conclusions, and the true view of the matter. Mallet says;—

"Every melting mixes it up with more or less finely divided oxides and silicates, in addition to which the earths, which are met with in the materials of the furnace, the fuel and the flux, often get reduced, and their bases in minute quantity alloyed with the iron. The conjoint effect of the foreign bodies and diffused oxides is to prevent the metal running clean in the moulds, or making sharp, sound castings; and the effect both of the diffused oxides and of the alloy with the metals of the earthy bases, is frequently to sensibly impair the ultimate cohesion of the cast iron.

"These evils are masked, or rather may be occasionally masked, by the increase of hardness, the approach towards white cast iron, which is produced by each successive cooling; but the combined effect is not that of improvement in the metal as a structural material, but a deterioration; for although it is, as is well known, a fact that the ultimate cohesion of white cast iron is much greater than that of grey or darker coloured metal, its coefficient of extensibility at rupture is a great deal less; in other words, the white cast iron is stronger, but not so tough.

"For these reasons, as well as others affecting the facility and perfection with which hard white cast iron is moulded, it is to mislead the practical iron founder to tell him that the oftener he melts and casts his good pig iron, up to 'thirteen times' at least, the better it becomes. In brief, the facts are these;—1st. Every additional melting of cast iron injures, or is likely to injure, its quality as a structural material by the addition of foreign substances. These reduce the value of the coefficient of resistance at rupture, and may or may not reduce that of ultimate extension; that is, the metal, by remelting, becomes weaker and may become more brittle. 2nd. Every additional cooling after melting increases the hardness, density, and coefficient of resistance at rupture of the metal as last melted, but constantly decreases the coefficient of ultimate extension, that is, the metal by recooling becomes stronger, but more brittle. The limit to these effects is found at the point where the whole of the cast iron has passed into the state of white cast iron, as it is produced in "the chill," or in the "finery ingot." The effects are more rapid as respects the melting in proportion as foreign bodies, having more powerful affinities and in larger quantities, are presented to the cast iron in the furnace; we may add also, as the nature of these bodies shall be more or less injurious when combined therewith; and as respects the cooling are more rapid in proportion as the rate of cooling is more so. 3rd. The conjoint effect of repeated and alternate melting and cooling thus may or may not result in a material possessing a higher coefficient of ultimate cohesion at rupture, but will always result in one more brittle, and thus of less in place of greater structural value. As respects the properties of the material in the iron founder's view, its moulding properties are always deteriorated. 4th. If the cast iron at the commencement be assumed to be very bright grey mottled iron, or white iron, then it is certain that the effects of every subsequent melting, under the ordinary conditions of cupola or air furnace, must prove deteriorative, and that only."

The principal and most objectionable impurities found in iron and steel are sulphur, phosphorus, silicon, calcium, and magnesium. Sulphur and calcium make iron brittle at a red heat; this is called "red-short" iron; phosphorus and silicon make it brittle at low temperature; this is known as "cold-short" iron.

The latter is the greater defect of the two. To avoid sulphur, use fuel which is free from sulphur; iron, which has been smelted, or puddled with charcoal, or with coke, that is, free from sulphur, is the strongest and toughest. Hence the high estimation in which "charcoal" iron is held.

Phosphorus comes either from phosphate of lime contained in the ore, the fuel, or the flux, or from phosphate of iron in the ore, phosphorus being most abundant in those strata where animal remains are found.

The presence of calcium and silicon can only be avoided by the use of ores that contain neither silica nor lime, such as pure hæmatite, or pure magnetic iron ore.

Silicon makes iron brittle and hard, and has a similar effect on it to phosphorus; it is constantly found in cast iron; hot-blast iron has more silicon usually than is found in cold-blast iron.

Alloys of iron are but of small importance to the founder. The following may be briefly noted;—

Chromium does not readily combine with iron, which it causes to be excessively hard.

Arsenic imparts a fine white colour to iron, but makes it brittle.

Gold combines very readily with iron; it serves as a solder for small iron castings, such as breastpins and similar articles.

Silver does not unite well with iron, but a little may be alloyed with it; it causes iron to be very hard and brittle. The alloy is very liable to corrosion.

Copper, if alloyed with iron, is not regarded as a homogeneous compound, but a small quantity of iron added to brass increases its tensile strength.

Tin, with iron, makes a hard, but beautiful alloy, and can be mixed in any given proportions, which, if nearly half-and-half, assumes a fine white colour, with the hardness and lustre of steel.

Alloys of iron are but seldom used at present, owing to the easy and economical ways in which it can be gilded, silvered, and galvanized, or coated with other metals.

Of the various brands of cast iron which are useful to the founder, Scotch pig iron is superior for most purposes to any other pig iron; a little Scotch No. 1 will give fluidity to inferior brands. Gartsherrie, Coltness, Langloan, Shotts No. 1, are in much demand on this account. This superiority may be partly attributable to the varieties of ironstone which occur in Scotland, and partly to the adaptability of Scotch coal under proper manipulation to produce No. 1 iron.

Coltness pig iron is almost exclusively used for foundry purposes, and is in very high demand owing to its high percentage of uncombined carbon, which makes it particularly suitable for mixing with the light grey qualities of charcoal iron produced on the Continent, and with old foundry scrap.

To good Scotch pig is frequently added a certain proportion, varying to suit the requirements of the case, of "all mine" Staffordshire iron.

Lilleshall pig iron is a celebrated cold-blast iron, remarkable for its strength and resistance to torsion and tensile strains in a manufactured state; hence it is generally kept in stock to be used as a mixture for the metal in any casting where strength is of primary importance, and it is also very largely used in foundries for casting into soft or hard chilled rolls.

The following list gives the names of a few of the most celebrated British makers of good melting pig iron. These have been selected for no invidious reason, as there are many others making excellent foundry pig whose names are unknown to the writer:—

Roberts and Co.	Tipton Green Furnaces. Make good melting iron for bedsteads, and forge iron.
H. B. Whitehouse	Prior Fields, Bilston. Best melters.
Bowling Iron Co.	Best melters.
J. H. Pearson	Windmill End, Dudley.
Cochrane and Co.	Dudley.
Madeley Wood Co.	Shropshire.
W. Baird and Co.	Gartsherrie, Scotland.
Coltness Iron Co.	Coltness „
Wilson and Co.	Summerlee „
R. Addie	Langloan „
W. Dixon	Govan „
Merry and Co.	Carnbroe „
Shotts Iron Co.	Shotts „
Barrow Hæmatite, Iron and Steel Company	Barrow. Iron for malleable castings.

In making ornamental casts, strength is of secondary consideration, but in machinery, and girders for structural purposes, it is of the first importance. In foundries where machinery is cast, or water-pipes, or beams for bridges, or architecture, there should be means of testing the strength of their cast iron. The safest and best way of doing this is to have a standard pattern, say a bar 2 ft. long, 1 in. thick, and 2 in. wide. This pattern is to be moulded in a particular flask, with uniformly dry sand, and cast inclined at a particular degree. The mixture of iron is made in a crucible melted in an air furnace. This proof-bar is fastened with one end in a vice, and at the other end a platform is suspended, upon which so much weight is piled as to break the bar. Its deflection or deviation from the straight line, or from its original position, is measured. In this way the relative strength as well as the degree of elasticity may be measured, and the relations of the strength of one mixture of iron to another mixture are decided with great practical certainty. Under all conditions a mixture of several brands of iron is stronger than the average strength of the whole, each taken by itself. It is rare, therefore, to employ only one kind of iron in the foundry. Generally mixtures are made, varied according to the nature of the objects to be cast, the work to which they will be applied, and the strains to which they will be exposed. It is the power of making mixtures which possess these qualities, of various kinds of iron in the casting, that forms the principal advantage of the second fusion. The founder can thus modify, entirely at will, the nature of the metal according to the exigences of his work, and apply to each object the quality of iron best adapted for it.

A thorough acquaintance with the different kinds of cast iron and the results obtained by their mixture constitutes one of the qualifications of a good founder. It is like many other things very difficult to acquire, and can only be the fruit of numerous observations and a lengthened experience.

The kinds of pig iron which should be mixed, to obtain the best results, depend very much upon the situation of the foundry, and the qualities of iron which are most easily and cheaply procured in the immediate neighbourhood, and as the nominal brands of iron differ considerably in quality in various localities, only a few general considerations can be mentioned, as in purchasing the buyer will have to be guided mainly by his experience, and the possibilities of obtaining an article as near his requirements as his position affords.

If pig iron is too grey, or too spongy, it may be improved by adding No. 3 iron, or scraps from old castings, which are preferable.

Very black grey iron will bear an addition of 30 per cent. of No. 3 pig or scrap. Iron which contains too little carbon is successfully improved by adding No. 1 until the wished-for strength and texture are obtained. Iron from different furnaces ought to be mixed together, and if there is any possibility of obtaining iron from different localities and different ores, it is to be preferred.

In all cases, however, it is better to mix No. 1 of one kind with No. 2, 3, or 4, or scrap of another kind.

A mixture which makes a close and compact grey iron is the best both for strength and economy, but in each instance proper consideration must be given to the purposes for which the iron is required, as it by no means follows that a mixture which is excellent for one class of casting is even tolerably adapted for another class. Thus iron which makes a sharp, clear casting for small ornamental work, could not with safety be used for parts of heavy machinery, or for beams and girders.

Small or ornamental castings require a fusible iron, not too grey, which will soon solidify and take a clear, sharp impression from the mould.

Iron which is a little cold short, containing a slight admixture of phosphorus, does well for such work; whilst for railings, or balustrades, or other purposes where the iron may be subjected to rather sudden strains, the pig should be fine grained, and free from phosphorus.

In order to obtain a metal having the utmost slipperiness of surface, manganiferous iron is strongly recommended. For heavy castings, where great tensile strength is required, spiegeleisen should not be used; but if an iron is required that will be good for turning and boring, as in the case of steam-engine cylinders, a manganiferous iron must be used in such proportions as will render it most suitable for undergoing these operations. Spiegeleisen alone does not give the right metal, as it contains from 8 to 10 per cent. of manganese, which is too large a proportion; 2 or 3 per cent. of manganese is the best for giving a good slippery surface, which will continue in the best order in working, and is consequently well suited for horizontal, stationary, and locomotive cylinders, and for other sliding surfaces. A metal possessing great fluidity in melting can be obtained by a mixture of North Lincolnshire manganiferous iron with hæmatite and a little Scotch pig; this gives a close metal, which, though difficult to file, can be turned and bored with facility. By the use of the simple ingredient manganese, added in proper proportions, iron for the exact character required for steam cylinders, slide valves, or motion bars can be obtained.

While ordinary cast iron emits sparks when run from the furnace, and often gives off occasional bubbles of gas during its cooling, iron containing manganese evolves so much combustible gas, that upon the surface of the metal while flowing from the furnace is a sheet of burning gas. While the iron is cooling the gas is discharged in numerous jets. Iron containing manganese retains after solidification much more hydrogen than cast iron. A specimen of each kind of iron weighing 500 grammes (17·635 oz.) heated in a vacuum to 1472° Fahr., gave off the following quantities of gas;—

	Charcoal Iron.	Spiegeleisen.
Carbonic acid	0·6	0·0
Hydrogen	12·3	27·0
Carbonic oxide	2·8	0·0
Nitrogen	1·0	2·5

The carburetted manganese takes up much more hydrogen than iron carburetted to the same degree. It is seen, then, that the presence of manganese in cast iron increases materially the occlusion of hydrogen, and diminishes that of carbonic oxide.

A very good mixture for strong and close-grained cast iron for steam cylinders is composed of 8 parts, by weight, charcoal pig, No. 5; 10 parts, by weight, Scotch pig; 10 parts, by weight, scrap iron. Another is made of the following irons—Blaenavon (cold blast), Silverdale (Madeley Wood), Hæmatite, No. 7 or 8, and Glengarnock mixed with good scrap in varying proportions

Where great hardness is required, an excellent mixture is 2 parts charcoal pig, No. 5; 4 parts Scotch pig; 30 parts scrap.

In order to get a perfectly homogeneous mixture, and at the same time to have the power of thoroughly examining the metal before finally casting, it is advisable to melt the metals together first, and cast in small ingots or pigs, which can be easily broken for testing and examination. If the mixture proves satisfactory, it can then be remelted, and cast in the mould. Such a precaution will often save the production of waster castings.

When a tough, close-grained casting is required, borings and turnings of wrought iron are often put in the cupola along with the broken pig. An instance of such a mixture is when a powerful hydraulic cylinder is to be cast, for unless the metal is very fine in the grain it will be useless for the purpose. Care and judgment exercised in the preparation of the charge of metal for the cupola will always bring its own reward and substantially add to the reputation of any foundry.

Morris Stirling had a process for making tough iron, which consisted in putting pieces of wrought iron into cast iron, and passing them through the furnace together. Most practical iron founders have some particular mixtures of iron to which they attach great importance, and with reason, for upon the judicious union of different brands of iron the ultimate value of the casting for its special purpose mainly depends, and as carriage is an expensive item in dealing with so weighty a material, that which is lightest is, other things being equal, the best iron to employ.

Table 2 will be found of service, as it exhibits the percentage of carbon and silicon contained in various kinds of cast iron, and for comparison similar particulars of some wrought irons and steel.

TABLE II.—PERCENTAGE OF CARBON AND SILICON CONTAINED IN VARIOUS KINDS OF CAST AND WROUGHT IRON AND STEEL.

Description.	Carbon.	Silicon.	Authority.
	per cent.	per cent.	
Spiegeleisen (New Jersey, U.S.)	6·900	0·100	Henry.
„ (German)	5·440	0·179	Schafhäutl.
„ (Musen)	4·323	0·997	Fresenius.
Löfsta pig iron (Dannemora, Sweden)	4·809	0·176	Henry.
Grey pig iron, No. 1 (Tow Law)	2·795	4·414	Riley.
„ „ (Acadian Iron Co.)	3·500	4·840	Tookey.
Grey foundry pig iron, No. 1 (Netherton, South Staffordshire)	3·07	1·48	Woolwich Arsenal.
Ditto ditto, No. 2, ditto	3·04	1·27	„
Grey forge pig iron ditto	3·12	1·16	„
Forge pig iron, ditto	3·03	0·83	„
Strong forge pig iron ditto	2·81	0·57	„
Grey pig iron (Dowlais)	3·14	2·16	Riley.
Mottled ditto, ditto	2·95	1·96	„
White ditto, ditto	2·84	1·21	„
Mottled pig iron (Wellingborough)	2·10	2·11	Woolwich Arsenal.
White pig iron (Blaenavon)	2·31	1·11	Percy.
Refined iron (Bromford, S. Staffordshire)	3·070	0·630	Dick.
Puddled steel, hard (Konigshütte)	1·380	·006	Brauns.
Ditto ditto, mild (South Wales)	·501	·106	Parry.
Cast steel, Wootz	1·34	..	Henry.
„ for flat files	1·2	..	A. Willis.
„ (Huntsman's) for cutters	1·0	..	„
„ for chisels	·75	..	„
„ Die steel (welding)	·74	..	„
„ double shear steel	·7	..	„
„ quarry drills	·64	..	„
„ masons' tools	·6	..	„
„ spades	·32	..	„
„ railway tires	32 to 27	..	„
„ rails	26 to 24	..	„
„ plates for ships	·25	..	Various.
„ very mild „ (melted on open hearth	·18	..	A. Willis.
Hard bar iron (South Wales)	·410	·080	Schafhäutl.
„ „ (Kloster, Sweden)	·386	·252	Henry.
„ „ (Russia)	·340	trace	„
„ „ „	·272	·062	„
Boiler plates (Russell's Hall, South Staffordshire)	·190	·144	„
Armour plates (Weardale Iron Co.), too steely	·170	·110	Percy.
Bar iron (Löfsta, Sweden)	·087	·115	Henry.
„ (Gysinge, Sweden)	·087	·056	„
„ (Osterby, Sweden)	·054	·028	„
Armour plates (Beale & Co.)	·044	·174	Percy.
„ (Thames Iron Co.)	·033	·160	„
„ (Low Moor)	·016	·122	Tookey.

It seems scarcely possible to exaggerate the importance in designing iron castings, of so arranging their outlines as least to interfere with the natural laws of crystallization, which come into play during the cooling of the metal.

It is of vital importance that anyone who may have to design castings should thoroughly understand the problem, "How does the shape of the casting allow the lines of crystallization to flow so as to keep them in the most compact form, and so that the molecules are not separated by any unnatural force?"

The following remarks on crystallization will have no reference either to iron or steel, when it has undergone the process of either rolling or hammering, for these so re-arrange the molecules as to direct them from their natural flow, just as when they pass from a liquid to a solid state. We must therefore confine our attention to metals passing from the liquid to the solid condition, by the act of crystallization; and more particularly to cast iron and brass, for it is to these that the founder has most frequently to direct his attention and to exercise his skill. Not unfrequently the founder gets the blame when some portion of a cast-iron structure has failed, even when no defects are apparent to the uninitated. It is asserted that the founders have not put good metal in the casting, for that it has been calculated from a proper formula, what quantity of material should carry the load required. At the same time it has not been considered in which way the lines of crystallization flow, nor by the addition of many excrescences to the casting, that they may have so distorted it as to render it comparatively a very weak thing.

Iron which has been poured into a mould, on changing from a liquid to a solid state, becomes a mass of crystals. These crystals are more or less irregular, but the form toward which they tend, and which they would assume if circumstances did not prevent, is that of a regular octahedron. This is an eight-sided figure, and may be imagined to be formed out of two pyramids, having their bases together. In a perfect crystal of iron all the lines joining the opposite angles are of equal lengths and at right angles to each other. These lines are called the axes of the crystal. Concerning this formation of crystals, Mallet observes, "It is a law of the molecular aggregation of crystalline solids that when their particles consolidate under the influence of heat in motion, their crystals arrange and group themselves with their principal axes in lines perpendicular to the cooling or heating surfaces of the solid, that is, in the direction of the heat-wave in motion, which is the direction of least pressure within the mass.

"This is true, whether in the case of heat passing from a previously fused solid in the act of cooling and crystallizing on consolidation, or of a solid not having a crystalline structure, but capable of assuming one upon its temperature being sufficiently raised by heat applied to its external surface, and so passing into it.

"For example, if an ingot of sulphur, antimony, bismuth, zinc, hard white cast iron, or other crystallizable metal or atomic alloy, or even any binary or other compound salt, or hyaloid body, as sulphide of antimony, calomel, sal-ammoniac, various salts of baryta and lime, chloride of silver or lead, or even organic compounds, such as camphor and spermaceti, provided it only be capable of aggregating in a crystalline form under the influence of change of temperature, as from fusion or sublimation. If an ingot or mass of any such body be broken when cold, the principal axis of the crystals will always be found arranged in lines perpendicular to the bounding planes of the mass, that is to say, in the lines of direction in which the wave of heat has passed outwards from the mass in the act of consolidation."

Now, cast iron is one of those crystallizing bodies which, in consolidating, also obeys law more or less perfectly, according to the conditions, so that generally it may be enunciated as a fact, that in castings the planes of crystallization group themselves perpendicularly to the surface of the external contour; that is to say, in the direction in which the heat of the fluid cast iron has passed outward from the body in cooling and solidifying. This is because the crystals of cast iron are always small, and are never well pronounced. Their directions are seldom apparent to the eye, but they are not the less real. Their development depends;—

1. Upon the character of cast iron itself, whether or not it contains a large quantity of chemically uncombined carbon, suspended graphite, which Karsten has shown to be the case with all cast irons that present a coarse, large-grained, sub-crystalline, dark and graphitic, or shining spangled fracture. Such irons form in castings of equal size the largest crystals.

2. Upon the size or mass of the casting presenting for any given variety of cast iron the largest and coarsest aggregation of crystals, but by no means the most regular arrangement of them, which depends chiefly upon—

3. The rate at which the mass of casting has been cooled, and the regularity with which heat has been carried off by conduction from its surfaces to those of the mould adjacent to them; and hence it is that of all castings in iron, those called "chilled," that is to say, those in which the fluid iron is cast into a nearly cold and very thick mould of cast iron, whose high conducting power carries off the heat, present the most complete and perfect development of crystalline structure, perpendicular to the chilled surface of the casting.

In such the crystals are often found penetrating to 1½ in. or more into the substance of the metal, clear and well-defined.

In a round bar the crystals are all radiating from the centre; in a square bar they are arranged perpendicularly to the four sides, and hence have four lines in the diagonals of the square, in which terminal planes of the crystals abut or interlock, and about which the crystallization is always confused and irregular.

The direction of the crystalline radiation follows the planes of the figure, with but little exception or deviation. In a flat plate are diagonal lines of weakness, as in a square figure. The pairs of diagonals, joining the corners nearest to each other, are joined by a long line parallel to the two long surfaces. This line is also a line of weakness, as the lines in which the crystals assemble in the systems belonging to each surface begin at the surface, and, as the casting cools, elongate toward the centre. When they meet in the middle they do not form continuous lines through from one surface to the other.

Castings may be made which will not show this peculiar appearance, and may not have it in any marked degree, but if such castings are exposed to heat the crystals will change position, and assemble in lines perpendicular to the surfaces through which the heat entered the casting. The greater the heat the more marked will be this peculiar structure, and the law, as before stated, applies equally in this case, all the crystals finally assembling in lines perpendicular to the bounding surfaces which were heated.

This can be illustrated in the following manner ;—Take two pieces of zinc which have been rolled into a sheet, and heat one of them just below the melting point. To illustrate the point in question, it must be remarked that rolling any metal into a sheet elongates each crystal in a direction perpendicular to the pressure exerted in rolling, that is, lengthwise in the sheet, and if the metal is drawn into wire, the crystals are lengthened in the same way. By bending the piece of zinc that has not been heated, it will be found that it is tough, and can be bent many times without breaking the crystals lengthwise. Take the other piece of zinc that has been exposed to heat. In it the crystals have turned round, and have formed themselves in lines perpendicular to the surface through which heat entered, and it will break when it is bent. The peculiar crystalline structure is varied somewhat by the quality of the metal used, but it depends more directly upon the amount of heat passing out, or, in casting, upon the rapidity with which the operation is performed.

It may here be remarked that in casting large thin plates, such as flooring plates, it is the practice of the founder, when they are cast open, to cover them over with loose sand as soon as the metal ceases to be liquid; and then to remove the sand, so as to expose the surface of the metal to the action of the air in a crosswise direction; the object in doing so is the more rapidly to cool those portions where crystallization is longest in taking place. If this be not done, the plate not unfrequently buckles, and thereby loses its uniform level surface, or sometimes it actually splits asunder. One of the difficulties founders have is to keep large flat plates straight, or from flying into several pieces. Whenever, therefore, it is possible to cool them in the lines of the weakest points, and thereby to get the metal by rapid cooling, as near as possible to the other parts, so much the better. This cannot be done at all times, for it is occasionally not possible to uncover those portions of a casting without cooling other portions, which would thus cool too rapidly, and so cause a greater evil. Thus it is that sometimes much judgment is needed so as to suit the conformation of the casting, and to reduce the lines of crystallization into such forms as will in some measure avert destructive changes. In a large circular plate to which is attached a large portion of a cylinder, it would be most difficult to get the centre portion to cool, and thereby crystallize in the same ratio as the outer edge, for the heat is so much concentrated in the centre that those portions of the mould cannot be removed until crystallization has almost come to rest. It is of great importance that the proportions of the metal should be arranged so as to neutralize those two divergencies, and also to reduce the lines to a minimum. If a circular plate, 9 ft. diameter, be cast and cut from the edge to the centre, the contraction of the iron by crystallization gives an opening of 1¼ in. The neutral strain upon this plate must be very great, and many such castings fly into pieces upon the least heat acting upon them. It is therefore necessary to rearrange its formation so as to reduce the crystallization to a minimum. This can be done by slightly changing the form, and thus reducing the strain. This example shows how important it is to pay strict attention in the following out of natural laws.

The principal axes of the crystals in a cylinder should be all directed to the centre. They therefore gradually change their direction, and thus no planes of weakness are produced. These considerations explain the general law as applied to cast-iron artillery, and which is as follows ;—"That every abrupt change in the form of the exterior, every salient, and every re-entering angle, no matter how small, upon the exterior of a cylinder, gun, or mortar, is attended with an equally sudden change in the arrangement of the crystals of the metal, and that every such change is accompanied with one or more planes of weakness in the mass."

The natural remedy for this is to avoid all sharp angles, allowing the metal, when possible, to flow in curved lines instead of sharp square corners.

The square projections of the "ventfield" produce at each angle planes of weakness which, in the case of re-entering angles, penetrate deep into the body of the gun. That these planes really do exist is evidenced by the lines of fracture in bursted guns, which almost always follow along the angles of the sides of the "ventfield." The same may be said of hydraulic cylinders when a boss is cast on, whereto to affix the connecting pipe and the pumps, and also in the trunnions of guns. A gun, like every other metallic substance that fails under strain, must fail in the weakest place, and the places of fracture and position of these planes of weakness coincide most remarkably. The conclusion, therefore, seems inevitable, that, however incapable the unaided eye may be to discover any differences in the crystalline arrangements of the various parts of castings, such planes of weakness do exist in the positions and from the causes pointed out.

To obviate two unfavourable conditions, it is best to cast a cylinder or tube hollow, to suspend the core of the mould from the top or head, insert a perforated tube down the interior of the core, and then inject a current of cold air into the interior of the casting. In America some use water to cool such interiors; cold air is, however, as most easy of application, less dangerous and more effective. The fact is that by injecting cold air down the core, the central heat is reduced and placed on an equality with that of the external surface, thereby getting rapid crystallization. The densities of the outer and inner surfaces are also thus made uniform with each other.

Now as regularity of development of the crystals in cast iron depends upon the regularity with which the melted mass cools, and the wave of heat is transmitted from the interior to its surface, arranging the crystals in the lines of least pressure in its transit, so the extent of development, or, what is the same thing, the size of each crystal, depends upon the length of time during which the process of crystalline arrangement goes on, that is to say, upon the length of time the casting takes to cool.

The lower the temperature at which the fluid cast iron is poured into the mould, and the more rapidly the mass is cooled down to solidification, the closer will be the grain of the metal, the smaller the crystals, the fewer and less injurious the planes of weakness, and the greater the specific gravity of the casting. The very lowest temperature at which metal can be poured, so as to fill every cavity of the mould without risk of defect, is that at which a large casting, such as a heavy gun, a hydraulic cylinder, or a large anvil block, ought to be produced. It is here, however, that the difficulty of the founder begins, and especially where castings of a complicated form are required. The point, then, is to get every portion of the mould filled without cold shots, or collections of impurities arising in the metal from eddies or other obstructions. It is thus an absolute necessity to have the metal as liquid as possible, and to get the mould filled as rapidly as it can be done. Founders know well that accumulations of a deteriorating kind occur with dull metal and slow running; and experience has taught that castings are much more free from defects, both of cold shots and impurities, by using hot metal, although the crystallization is not so perfect in heavy castings.

Irons are often melted together, having different degrees of fusibility; they will perhaps mix, but not combine properly with each other.

These irons, having different melting points, will shrink unequally, and not having become united into one homogeneous body, but existing separately, each one will pull the other, and, if possible, pull completely away, causing the casting to break. No. 1 iron has a higher melting point than No. 2, made from the same ores, and not only do different grades of iron shrink differently, but of castings poured from the same metal, a small casting will shrink more than a heavy one. Excess of heat in every case, however, increases shrinkage. The lower the melting point the less shrinkage. Experiments show, as in the case of other alloys, that a mixture of two brands of iron may have a lower melting point than either of them when used separately, and on the other hand, a mixture of a number of brands of iron may have a higher melting point than any one of the brands used singly. It is generally considered that charcoal iron has a higher melting point than coke iron. Following up the statement that of castings poured from the same iron, the light shrinks more than the heavy casting, it follows that in making a pattern no part should be thicker than another. Of course it is not possible in practice to adhere to this axiom. Much, however, may be done to avoid very sudden contractions in shape.

Chill-casting.—Chill-casting converts into white iron the outer skin of a casting made from certain qualities of cast iron; the depth to which this alteration extends is capable of being regulated. This white cast iron is very hard, brittle, and crystalline, and scarcely differs either in chemical or physical properties from steel, except that it cannot be tempered. In this case the whole, or nearly the whole, of the carbon contained in the iron is in a state of chemical combination with it; whilst in the darker irons most of the carbon is diffused throughout the mass in the form of small particles or scales.

If the cast iron contains a large proportion of manganese, the amount of combined carbon may be as much as 10 per cent., but ordinary pig iron seldom contains more than 5 per cent. of combined carbon. These particles of uncombined carbon must, whilst the metal is in a melted state, be combined with it, for being of a much less specific gravity, less than half, if they were floating about in separate particles, they would necessarily come to the surface of the metal. It is therefore assumed that the separation of the particles of carbon takes place at the moment of solidification.

If a thin sheet of grey cast iron is rapidly cooled, it becomes whiter, that is to say, a larger proportion of its carbon is held in chemical combination. White cast iron may also be obtained from grey pig, by alternately melting and cooling it in the ordinary manner. When it is desired to obtain a white iron direct from the blast furnace, the proportion of fuel is reduced below the amount usually allowed for the same quantity of ore and blast, if a good grey iron were required.

These facts explain the results which are obtained by the process of chilling a casting; where the skin of the casting is in contact with the chill, it is, for a certain distance in, converted into a hard white iron, whilst the interior of the casting will remain of the same general nature as to colour and toughness as the pig from which it was cast. The sudden cooling of the metal prevents the combined carbon near the outer portion from separating, whereas the cooling of the inner portion of the metal being more gradual, allows it to resume its normal condition. The suspended particles of carbon which are held in the metal near the exterior of the casting, are supposed to be forced inwards into the interior, or still fluid portion, of the casting.

All, or nearly all, the carbon in the chilled portion of the casting is therefore in chemical combination with the metal, whilst that in the interior remains suspended as separate atoms or scales. Such is the generally accepted theory of chilled castings, which may indeed be open to objection; the practical result is, however, beyond any question.

Chill-moulds differ from the ordinary moulds in having to be made so as to admit the chill. That in which a railway wheel is cast consists of three boxes. The lower is a box of common round form, merely to hold the sand and give support to the centre core and the middle box. The upper box is of a similar form, also round. The middle box is a solid ring, cast of mottled iron, and bored out upon a turning lathe, giving its interior the reverse of the exact outer form of the rim of the wheel. This middle box ought to be at least as heavy as the wheel is to be after casting, and it is preferable if it has two or three times that weight. All the three boxes are joined by lugs and pins as usual, and the latter ought to fit well without being too tight. The chief difficulty in casting these chilled wheels, is to make the cast of a uniform strain to prevent the wheels from breaking, and wheels with spokes or arms are very liable to this.

At present most of these wheels are cast with corrugated discs or plates; in this way the hub may be cast solid, and the wheel is not so liable to be subjected to an unequal strain in the metal as when cast with spokes. In such plate-wheels the whole space between the rim and the hub is filled by metal, which, however, in most cases is not more than $\frac{3}{4}$ in. or 1 in. thick. The rim of a good wheel should be as hard as hardened steel at its periphery, but soft and grey in its central parts. The first requisite is more safely attained by having a heavy chill; but if the chill is too heavy, the inner parts are apt to suffer from the cooling qualities of the chill. Success in this branch of founding depends very much on the quality of the iron of which the wheels are cast. Soon after casting such wheels it is advisable to open the mould, and remove the sand from the central portion, so as to make it cool faster; this precaution saves many castings, not only in this particular case, but in many other instances. Uniformity in cooling is as necessary to success as good moulding.

Chilled rollers are the most important examples of chilled castings. The mould for a chilled roller consists of three parts. The lower box of iron or wood is filled with new sand, or a strong composition of clay and sand, in which a wood pattern is moulded, which forms the coupling and the neck of the roller. The middle part of the mould is the chill, a heavy iron cylinder well bored. The upper part of the mould again consists of a box, but is higher than the lower box, so as to make room for the head in which the impurities of the iron, sullage, are to be gathered. The two boxes with their contents of sand must be well dried. In some establishments the two ends of the roller are moulded in loam, over the chill, to secure concentricity of roller and coupling; but this can be quite as safely arrived at by fitting the ears and pins of the boxes well to the chill. The chill is the important part in this mould; it ought to be at least three times as heavy as the roller which is to be cast in it, and provided with wrought-iron hoops to prevent its falling to pieces, for it will certainly crack if not made of very strong cast iron. The iron of which a chill is cast is to be strong, fine-grained, and not too grey. Grey iron is too bad a conductor of heat; it is liable to melt with the cast. Iron that makes a good roller will make a good chill. The face of the mould is blackened like any other mould, but the blackening must be stronger than in other cases, to resist more the abrasive motion of the fluid metal. The chill is blackened with a *thin coating* of very fine blacklead, mixed with the purest kind of clay; this coating is to be very thin, or it will scale off before it is of service.

The most important point in making chilled rollers is the mode of casting them, and the quality of iron used. To cast a roller, whether a chilled roller or any other, from above, would cause a failure. All rollers must be cast from below. It is not sufficient to conduct the iron in below; there is a particular way in which the best roller may be cast, for almost every kind of iron. In the general mode the gate is conducted to the lower journal of the roller, and its channel continues to a certain distance around it. It touches the mould in a tangential direction. In casting fluid metal in this gate the metal will assume a rotary motion around the axis of the roller, or the axis of the mould. This motion will carry all the heavy and pure iron towards the periphery, or the face of the mould, and the sullage will concentrate in the centre. It is a bad plan to lead the current of hot iron upon the chill, for it would burn a hole into it, and melt chill and roller in that place together. The gate must be in the lower box, in the sand or the loam mould. The quality of the melted iron modifies in some measure the form of the gate; stiff or cold iron requires a rapid circular motion, while fluid thin iron must have less motion, or it is liable to adhere to the chill. The roller must be kept in the mould until perfectly cool, but the cooling may be accelerated by digging up the sand around the chill.

Many anvils, vices, and other articles are made of cast iron, mounted with steel; the welding together of steel and cast iron is not difficult if the steel is not too refractory. This process will not succeed well with shear steel, and hardly with blistered steel; but it is easily performed with cast steel, by soldering it to cast iron by means of cast-iron filings and borax. The cast-steel plates to be welded to the faces of anvils, are generally from a half to five-eighths of an inch thick, and as wide as the face itself. These are ground or filed white on one side, and then covered on that side with a coating of calcined borax. The plate, with the borax on it, is heated gently until the borax melts, which covers it with a fusible transparent glaze. The plate in this condition is laid quite hot in the mould, which latter is made of dry and strong sand. The iron is poured in and rises from below; the steel plate being the lowest part of the mould, it will have the hottest iron. The heat to be given to the iron will depend in some measure on the quality of the steel; shear steel requires hotter iron than cast steel. The cast iron used for these purposes should be strong and grey, but not too grey, or the union of the iron and steel is not strong. White cast iron will not answer in this case, partly because the casting would be too weak, but chiefly because the cast iron would fly or crack, in hardening the steel. The hardening is done under a considerable heat, with an access of water falling from an elevation of 10 ft. or more.

Chills are almost always made of cast iron, in a few exceptional cases only is wrought iron substituted.

The greatest practical advantage to be derived from the process of chilling, is in cases where a union of several opposite qualities is desired in the same casting. It would be difficult to overestimate the value of the combination in a pair of chilled rolls, for instance, of an exterior as hard and dense as hard steel, capable of being turned or cut to a smooth polished surface, with an internal core, so to speak, of the best soft tough cast iron.

The chilled portion of the casting is of a higher specific gravity and harder than the interior, uniform in texture, and crystalline.

Even where the metal employed in the casting was originally a white iron, the chilled portion is found to be rather harder, and its crystalline formation more regular. Such a metal as white cast iron should not, however, be employed for chilled castings, as the interior would not be so tough and strong as it should be.

Dark grey irons are not at all adapted for the purposes of chilled castings, No. 1 Scotch pig being particularly unsuitable; when the right quality of iron cannot be obtained, it is sometimes necessary to melt up a suitable proportion of hard white scrap cast iron with the soft dark grey iron, which alone would scarcely chill at all.

Hard, tough, bright grey, or mottled pig, having small crystals and a good uniform texture, are well adapted for the purpose, provided they do not contain an excess of uncombined carbon; the presence of manganese in the pig iron, or the addition of a little spiegeleisen, improves the quality of the castings.

Where the shape and size of the casting are such that the mass of metal in the interior will long retain its heat, much of the effect of chilling is lost; the greater the proportion the chilled surface bears to the size of the casting, the more effectual the chilling will be. The depth to which the chill may be formed in castings admits of a certain amount of regulation, but there are also circumstances affecting the castings which are at times almost beyond control.

It is not at all times possible to obtain the right quality of iron; the size and shape of a casting cannot always be well adapted for chilling; or the chill-moulds may not be of sufficient depth of metal, to conduct away the heat from the molten metal with the necessary rapidity, to allow it to solidify without being again melted, by the radiation of heat from the still molten metal in the interior.

Assuming a cylindrical casting of some 8 or 10 in. diameter, a depth of chill of at least 1 in. can be obtained, provided the metal employed is at all fit for the purpose, and with the iron best suited for chilling a much greater depth can be obtained, with proper care as to the moulds and the like. But in the great majority of cases 1 in. depth of chill is sufficient.

For castings that will have much surface wear, such as in rolling metal, or crushing minerals, allowance should be made in the depth of the chill for the removal of the exterior of the rolls, by their repeatedly being turned in the lathe, as their surfaces become worn or injured in use.

At the same time it must be remembered, that the greater the depth to which the chill is carried the more brittle is the casting. The chief strength of the casting is in its tough, unaltered metal beneath the hard chilled surface.

In considering the advisability of the greater or less depth of chill, therefore, estimate the extent to which the casting may be worn or turned before it becomes necessary to replace it.

Avoid chilling to a greater depth than necessary, especially in cases where strength is required in the castings, to resist transverse and other strains.

In casting large chilled rolls, the moulds for the ends and necks should be of dry sand, or loam, properly built up and connected with the iron chill for the roll itself. Or the iron chill for the ends and necks can be made much thinner and lighter in substance than that for the centre.

The mass of metal in the chill largely influences the depth of the chilled portion of a casting; it is necessary not only that it should be sufficient to reduce the temperature, in a few minutes, of the iron on the surface, from the temperature at which it is poured, say 2500° Fahr., to that of solidification, say about 1000°, when it is bright red in daylight, but also that it should be capable of absorbing the heat which will radiate from the interior of the casting, so as to prevent the solidified and chilled surface from being remelted by the radiation of internal heat.

Moisture in moulds is at all times dangerous, but when these are made of sand or loam, the danger is lessened to a certain extent, by the porous material allowing of the escape of some of the pent-up gases and steam generated by the intense heat of the cast metal.

When, however, chill-moulds are used, the utmost precaution is required to have them absolutely dry for use.

This entire freedom from moisture could scarcely be obtained, still less preserved, in the warm, damp air of a foundry, with perspiring workmen hurrying about; the steam and vapour would at once condense on the surface of an iron chill-mould, if it were brought *cold* into the shop. Consequently the chill is always heated to a considerable extent before pouring, a precaution which it is all the more necessary to observe, when the chill is to be used in conjunction with sand or loam moulds. If this were not done, any dampness left in the sand or loam would probably be driven out, and at once condense on the surface of the chill, if that were not heated to a temperature considerably higher than that of the surrounding atmosphere.

The steam and gases which would be formed in a *damp* chill-mould, when the metal was poured, having no means of escape, would acquire tremendous expansive force, and would either burst the mould and send the liquid iron spirting about amongst the founders, or at least, ruin the casting and distort the mould.

It would appear that to heat the mould would impair its property of chilling the metal poured into it. Yet in practice it is not found to have this effect even when heated to 250° Fahr.

It is even asserted that a superior chill is obtained from a hot mould than from a cold one, other things being equal; it must be remembered that with a mould heated even to 250°, there is a large margin of difference between that temperature and that of the melted iron poured into it, and it is supposed that the chill has a greater tendency to conduct away heat from the metal cast in it, if the chill be previously heated to about the temperature above named.

The heat given out by the cast metal penetrates through the chill with extraordinary rapidity, and if the walls of the chill are not sufficiently thick to absorb the greater portion of the heat, considerable risk is run, that either the casting and the mould may fuse together in one solid mass, or that the effect of chilling may be neutralized, by the heat evolved from the central portion of the casting not being conducted away with sufficient rapidity. It may be assumed that cast iron expands slightly at the moment when it passes from the liquid to the solid form, such expansion, of course, tending to burst the mould.

To avoid these evils, the mass of the chill must be properly proportioned to the area of the portion of the casting which requires to be chilled, in relation to its entire bulk. In the case of a casting which has to be chilled over its entire surface, the weight of the chill-mould should be about three times that of the casting to be made from it, presuming the casting not to be of exceptionally large dimensions.

So varied, however, are the circumstances under which chill-moulds have to be employed, that experience is almost the only possible guide for their construction.

It is desirable not to make the chill-mould thicker than is necessary to enable it to carry off the amount of heat from the casting, from the fact that the thicker it is the more liable it is to crack, from the severe strains put upon it by the expansion of its inner portion, when the great and sudden heat of the molten metal first comes upon it.

This expansion and the subsequent contraction in cooling cannot but be unequal, and the larger and thicker the chill-mould, the greater is the risk of a fracture.

In the preparation of large chills it is always advisable to shrink wrought-iron hoops round them where possible.

Certain results have to be decided upon beforehand, and the founder must use his utmost skill to attain them in the safest and most economical manner; the utmost that science can do to assist him consists in pointing out what evils to avoid, or how best to rectify the damages occasioned by want of judgment or scientific knowledge.

In a foundry where many chilled castings from different moulds have to be made, it will be apparent that it is to the interest of the founder not to make these chills any larger, or heavier, than is absolutely necessary to effect the desired result; cost of the metal in the moulds, and the amount of room required for their storage, sufficiently explain this.

There are several ways of finishing the interior surfaces of the chill-mould before using it for casting.

For fine castings the mould must either be bored or machine planed, after which a coat of rust is allowed to form upon it; this is obtained either by wetting it for a few days with dilute hydrochloric acid, or with urine. The object of this coat of rust is to prevent the casting from adhering to the chill, but no "clay wash" must on any account be applied to the chill, as it would hinder its absorption of heat from the casting, and the rust itself must also be rubbed away for the same reason. When the surface of the chill has been thus prepared, and just previous to the casting, a thin, even coating of blackwash, or blacklead, is applied. If, however, the surface of the chill has been tolerably well oxidized beforehand, this coating may be dispensed with, although, as a rule, founders prefer to apply some kind of wash before pouring.

As the iron which is best adapted for chilled castings does not flow very freely, it is necessary that it should be at a high temperature at the moment of pouring, more particularly as it will have to part with its heat so rapidly on entering the mould, that it may solidify in irregular blotches, or clots, if it has not a sufficient store of surplus heat to keep the whole of the mass of metal in a liquid, or nearly liquid, state until the completion of the pouring.

For the same reason, the casting arrangements should be such, that the mould may be rapidly filled by a large stream or streams of metal, so directed, however, as to avoid, as far as possible, coming into continued and violent contact with the surface of the chill, which would thus soon become seriously damaged at such points of contact. The life of a chill-mould depends considerably upon the care with which it is used; if its surface becomes slightly damaged from the action of the molten metal, it may be patched up with a little loam, but wherever such patching occurs, the uniformity of the chill on the casting will be destroyed.

For fine work, or for castings where dimensions must be strictly adhered to, a very slight damage to the mould is fatal to it.

In many cases, however, when the mould is only slightly roughened in parts, it can be rebored, and made to do duty again. Of course, care must be taken not to remove a thicker skin of the mould than is necessary to get a smooth, even surface.

In the choice of the metal used for the chill-moulds, the founder has to consider whether he will be guided in his selection by economy or durability.

If the mould is likely to be one in great request, he should choose a hard, dense, close-grained pig iron from which to cast it, in fact, as we have before said, a metal very similar to that described as most suitable for the chill-castings themselves.

In other cases, however, not much care need be exercised in the selection of the metal for the chills, except that very dark Scotch iron, which is not at all suitable for the chilled castings, is also not well adapted for the chill-moulds.

It is impossible to lay down rules as to the exact dimensions of a chill-mould which is required to produce a certain-sized casting. In addition to allowance for the shrinkage of the casting on cooling, the sudden expansion of the mould itself, when the hot metal enters it, must be taken into account.

That part of the mould which first receives the flow of the hottest metal, not only expands most from having to bear the first sudden increment of heat, but has also to bear the weight due to the head of metal afterwards poured in, until the casting has cooled and solidified sufficiently to relieve the mould of this pressure. Consequently, it may be inferred that the actual dimensions of a casting will be that of the interior of the chill-mould, when it has been expanded to the extent due to the temperature of molten cast iron, when just on the point of solidification, minus the amount of subsequent contraction of the casting, during the process of cooling down to the temperature of the atmosphere.

The metal being poured into the chill, two actions immediately set in; the skin of the casting solidifies, and the metal in the interior commences to part with its heat, contracting away from the interior of the mould as it does so. The mould, at the same time absorbing heat, expands away from the exterior of the casting. The moment when the distance between the chill and the casting has reached its maximum, is, theoretically, the time when the casting should be removed from the mould. Experience, and the nature of the work in hand, must guide the moulder as to the safest time to withdraw his casting; if he attempts to do it too quickly, he may distort its shape, from its being as yet too hot and soft to bear the strain; if he leaves it too long, the chill-mould may have commenced to contract round the casting, and thus bind it hard and fast, besides having spoilt the chill surface, as before described. The higher the temperature of the cast iron when poured, the greater is the strain upon the chill.

The contraction of the casting during cooling depends less, perhaps, upon its absolute bulk than upon its form; and, as might be expected, a chilled casting contracts somewhat less in the cooling than an ordinary casting.

The principal elements which govern the amount of expansion in chill-moulds may be briefly stated as follows;—

Its internal capacity: the larger the quantity of molten metal it will have to contain, the greater the strains it will have to bear, from the longer sustained heat, and the greater pressure of the head of metal, before it has superficially solidified.

Its thickness: for large castings it is imperative that the chills should be thick in the walls, but with every increase of thickness the risk of cracking the chill is increased, owing to the tendency of the heated inner portion to expand, being opposed by the rigidity of the outer and cooler portion.

Having withdrawn the casting from the mould, it should be allowed to get quite cold as soon as it possibly can by radiation. No artificial cooling, by cold water, or the like, should be resorted to, as they are liable to distort or fracture the casting; and no further increase of hardness can be obtained in this manner.

Chilled cast iron and cast steel, similar as they are in many respects, have this important difference, that the one, cast iron, cannot be hardened by plunging hot into cold water, whilst the other, steel, can be hardened in that manner.

Avoid placing the casting in such an attitude, or in such a locality, as to expose it to undue strains, or to currents of air, or other circumstances likely to produce distortion or unequal cooling.

It has been mentioned that a chill-casting which has been allowed to cool down in the mould too slowly, owing to the chill not being sufficiently massive for its duty, or for other reasons, loses much of its chilled character, allowing a considerable portion of its contained carbon to pass into its former uncombined state, and the iron, instead of being hard and white, more nearly resembles the character of the pig from which it was originally cast.

Occasionally this quality is made serviceable, where it is convenient to use iron moulds, but where it is not desired that the resulting casting shall be hard or chilled. In such cases a pig iron may be selected which is of a bad chilling nature; or after the casting has been made in the chilled mould, it may be rendered soft and tough by being kept for several days at a low red heat.

Chills, when out of use, should be protected from rust by being greased and stacked under cover. Before being again used, the grease must be thoroughly removed, as it has a tendency to cause the casting to solder to the chill.

We conclude this article with a description of the American plan of making railway wheels, in which chilling in casting is employed to an extent unknown in any other industry.

The manufacture of chilled cast-iron railway wheels has now become a very important industry in the United States, upon whose railway system of 75,000 miles no other class of wheel is employed to any great extent, at least for passenger and freight rolling stock. There are a large number of cast-iron wheel works in the country, varying in capacity of production from 450 down to 40 or 50 wheels a day, and such improvements have been introduced into the manufacture that, whereas some time since railway accidents arising from broken wheels were common, of late years such a mischance is almost unknown. One of the most important improvements in the process of manufacture, consists in mixing with the pig iron a certain proportion of Bessemer steel, crop ends of rails being most conveniently used for this purpose. This mixture, besides improving the chilling qualities of the wheel, adds greatly to its strength, and even allows of the use of anthracite in the place of charcoal pig iron.

At the works of Messrs. A. Whitney and Sons, of Philadelphia, one of the largest establishments for the manufacture of chilled wheels in the United States, the different processes have been brought to a high degree of perfection. The following is a brief description of the factory, and the manner in which the work is advanced from stage to stage. Of course the foundry is the most important portion of the whole works. It is a fine building, 450 ft. long and 50 ft. wide, with two lines of rails running down its whole length, except opposite the furnaces. The rails are laid to a gauge of about 10 ft., and upon them are placed twelve light travelling cranes, with a platform attached to the centre post, and upon which the man working the crane stands, and controls its movements, both in hauling the moulds and ladles, and in moving the crane from place to place upon the line, the crane being geared for travelling. The floor of the foundry is so laid out that there is room on either side of both pairs of rails for a row of moulds, and in the centre of the building is a path about 4 ft. wide. Against one side of the building, and in the centre of its length, are five cupolas, three of 4 ft. 6 in. internal diameter, and two smaller ones of 18 in. in diameter. The former are employed in melting the iron for the wheels, the latter chiefly for experimental purposes. The three cupolas are tapped into converging channels, all running into one large tipping reservoir, from which the small ladles are supplied. The blast to the cupolas is furnished by a vertical blowing engine, with two blowing cylinders, one at the top of the machine and one at the bottom, with the steam cylinder between the two.

The mixing of the irons for the cupolas, is the most important and difficult operation in the whole course of the manufacture. Besides the steel scrap, nothing but charcoal pig iron is employed, and of this from twelve to twenty different kinds, all of the highest class, are used in varying proportions. But these mixtures have to be altered frequently, owing to irregularities in the nature of the metal, and daily tests are made with a view of ascertaining what changes, if any, have to be introduced into the next day's work. The proportions of the mixture being decided upon, the cupolas are charged, a ton of coal being first put in the bed of each furnace. The charge is then carefully loaded upon trucks, upon a weighing platform. Piles of the various pigs are placed in their proper order around the truck, and there is a drum upon the weighing machine, on which a sheet of paper is placed, and the weight of each different pig, in proper order, is written upon it. For instance, the workman commences with 250 lb. of coal in his truck; he then places 125 lb. of old steel rails, 125 lb. of cinder pig, 350 lb. of old wheels, and so on through the long list of charcoal pig irons employed, the old material being placed at the bottom of the furnace. The weighing platform is so arranged as to record the accumulating weights as the drum revolves, bringing before the workman the name and quantity of each successive ingredient which he takes from its respective heap before him. As soon as it is loaded, the truck is raised to the top of the cupola by an hydraulic lift. The moulds, when ready, are placed down the building in four rows, one on each side of the two lines of rail upon which the cranes run. The patterns used are almost all in iron, and the chills in the moulds are of cast iron. One workman can, on an average, mould ten wheels a day, but all failures in the casting, arising from any carelessness in moulding, are charged to him on a rapidly increasing scale.

This system has been found necessary, as the men are paid by the piece, and if only the price paid per wheel were deducted for the spoilt castings, a far higher average of failures would result, because the men would earn higher wages by working faster and more carelessly.

Before the metal in the cupola is ready to run, a charcoal fire is lighted in the receiver before spoken of, in order to warm it, and also that when filled, the metal may be covered with charcoal, and oxidation checked. In a similar manner the ladles, of which there are a very large number employed, have burning charcoal placed in them, and they are coated internally in the usual way. These ladles are cylindrical pots made of sheet iron, and mounted each on a pair of wheels for facility of transport. On the sides of each ladle are two sockets, into one of which the end of a long iron handle is inserted for hauling it along the floor. Also at each end of the axle is a square hole, into which is placed the end of a handle with forked ends. The ladle being run up to the receiver, the latter is tipped over by the gearing attached to it, and the ladle is charged; it is then brought along the floor to the crane, which takes hold of it, the two square-ended handles before mentioned are inserted in the holes in the axles, the ladle is raised, and the iron is poured into the mould. The chilled portion of the wheel sets almost as soon as it comes into contact with the chills, and in a very short time after the casting has been made the flasks are removed, the sand knocked away, and the red-hot wheel is placed on a trolly to be taken to the annealing pits. This process is one of the most important of the series. If the wheel be allowed to cool in the open air, severe internal strains are created, which will sometimes be sufficient to destroy the casting, and open-air cooling was the active cause of failure in the early periods of this class of wheel making.

The annealing ovens are placed at one end of the foundry, and below the floor, the top of the ovens being at that level. Besides these ovens of very large diameters for extra-sized wheels, and chilled tyres, there are forty-eight pits ranged in six rows of eight each. These rows are divided into pairs, each pair of sixteen pits being devoted to the reception of one day's production, the period required for annealing being three days. By this arrangement, when the last two rows of ovens are charged, the first two rows can be emptied and refilled, so that the work proceeds without interruption, and in regular rotation. Two hydraulic cranes, with the booms revolving upon a fixed post, are placed upon the floor, and command the whole area occupied by the ovens. The boom of each crane is made double, and upon it runs to and fro a small carriage, from which hangs the chain, carrying at the lower end the hooks by which the wheels are handled. This attachment consists of three arms, with flattened ends turned over so as to grip the wheel. The upper ends of these arms are hinged together, and as they tend always to fall inward, they hold the wheel tightly, but by moving a single attachment the arms are thrown outward when it is desired to release the wheel. The motion of the cranes is controlled by one man, fixed stops being provided on the guiding apparatus, so that when the crane is adjusted for filling one oven, it remains in that position till it is thrown over to the next.

The ovens or annealing pits are cylinders of sheet iron $\frac{1}{8}$ in. thick, about 66 in. in diameter, and of sufficient depth to contain, easily, eighteen wheels with cast-iron distance pieces between them. They are lined with brickwork, and being of considerable depth, they descend into a lower floor. The lower parts are enclosed in a large rectangular chamber, one for each set of ovens. Within this chamber, and for a short distance above it, firebrick is used instead of ordinary brickwork as in the upper portions, and within the cylinder a circular foundation of brickwork is set, upon which are placed the wheels on being lowered by the crane. The whole of this weight then is transferred direct to the foundation of the building. At the end of each of the three rectangular chambers already mentioned is a furnace, and each chamber is divided down the whole of its length by a perforated flue; through these perforations the heat from the furnace passes and enters the lower ends of the ovens. These furnaces are required to prevent the too sudden cooling of the castings, but only $\frac{1}{4}$ ton of coal is burned for each full day's production. Flues leading to the chimney carry off the heated gases from the upper part of the ovens, and so the process of cooling is thus very gradually carried on, until at the end of three days the wheels are ready for removal. The three large annealing pits mentioned above are somewhat differently arranged. To save room, they are not carried down so low as the other ovens, but terminate at a height of about 7 ft. above the floor, each being supported upon a central column. When they are used, a fire is lighted in the bottom of each pit, the wheels are placed in and covered over, and the oven is allowed to cool gradually.

On being removed from the pit the wheels are taken into the cleaning and testing room. Here the sand is removed, and the wheels tested by hammering under a sledge, as well as by a small hammer, while the tread is cut at intervals by a chisel. The heavy blows to which the wheel is subjected never fail in detecting faults when such exist, and when they are discovered the wheel is removed to be broken up. About 10 per cent. of the whole production is rejected, but occasionally this proportion is very much higher.

In order to keep the quality of the wheels to the desired standard, a large number of test pieces are cast every day and submitted to examination. By this means an accurate knowledge of the nature of the wheels, the character of the chill, and other points, is obtained; the data are carefully recorded, and if tests are satisfactory the wheels corresponding to the test piece are delivered into stock. If not, they are returned to be broken up. The sound wheels finally are taken to the machine shop, where they are bored, and if desired fitted with their axles. The tools, therefore, in this shop are few in number, consisting of three boring machines, a press for forcing the wheels on or for drawing them off the axles, and a number of lathes.

The capacity of Whitney and Co.'s foundry is 250 wheels per day.

The average life of a chilled cast-iron wheel of first-class quality is asserted to be 50,000 miles for passenger, and 100,000 miles for goods traffic. This is a high average, and probably many wheels fail before they attain this mileage. The common mode of failure is a breaking away of the surface of the tread in spots, until large portions of the chill become pitted in shallow holes. The exact cause of this failure has not yet been ascertained. In some cases such wheels are turned down to a smooth surface, and again placed in service.

Malleable Cast Iron; Case-hardening.—The manufacture of what are known as "malleable castings" consists in obtaining a tough, soft, flexible material, resembling wrought iron, from white brittle castings, by what is known as the cementation process. Some means of arriving at the same result appear to have been familiar to iron workers in the Middle Ages, as there are numerous examples of malleable castings to be found in old buildings, but Samuel Lucas, of Sheffield, appears to have been the pioneer in modern times of this important branch of the iron trade. He obtained a patent in 1804 "For a method of separating the impurities from crude or cast iron without fusing or melting it, and of rendering the same malleable and proper for several purposes for which forged or rolled iron is now used; and also by the same method of improving articles manufactured of cast iron, and thereby rendering cast or crude iron applicable to a variety of new and useful purposes."

A short description of the process is thus given in 'The Repertory of Arts';—"The pig or cast iron being first made or cast into the form most convenient for the purpose for which it is intended, is to be put into a steel-converting or other proper furnace, together with a suitable quantity of ironstone, iron ore, some of the metallic oxides, lime, or any combination of these, previously reduced to powder, or with any other substance capable of combining with or absorbing the carbon of the crude iron. A degree of heat is to be then applied, so intense as to effect a union of the carbon of the cast iron with the substance made use of, and continued so long a time as shall be found necessary to make the cast iron either partially or perfectly malleable, according to the purpose for which it is intended. If the casting is required to be perfectly malleable, from one-half to two-thirds of its weight of the other substances will be found necessary, but a much less quantity will suffice if partial malleability only is desired."

Towards the close of the process the heat must be very great. The duration of the heat, its degree, and the proportion of the substances to be employed, depend upon a variety of circumstances, "a knowledge of which," the patentee remarks, "can only be obtained by experience." For small articles the intensity and duration of the heat required to produce the malleability are less than for large castings. Such articles may be arranged in alternate layers with the other substances, separated, however, from actual contact by an intervening thin layer of sand.

Malleable cast iron will take a certain amount of polish under the action of emery and rouge, but not so good a polish as cast steel. In the lathe it works about as easily as wrought iron, but the tool blunts rather more rapidly. Thin pieces may be bent double when cold, but seldom can be bent back again without breaking. It can be forged to a certain extent when at a moderate red heat, but if heated much beyond that, it breaks in pieces under the hammer.

Two pieces of malleable cast iron may be burnt together at a temperature approaching fusion; or can be brazed to either wrought iron or steel with hard solder. If plunged red hot into water it is hardened, but to an uncertain and variable extent. Malleable cast iron is very soft, flexible, and far from brittle; it will only weld with difficulty, if at all; its fracture is dull grey, and uniform. Specific gravity about equal to cast iron, if anything a trifle less.

Most authors say it is decarburization by which cast iron is malleableized in this process, but Mallet doubts this, and remarks that by annealing white brittle cast iron either in hæmatite, chalk, or sand, we obtain not so much a chemical change as a molecular change in its constituent particles.

The uses for malleable castings are daily extending, and there is scarcely a trade connected with domestic or manufacturing appliances which does not largely employ this valuable material, so superior to ordinary cast iron for most purposes. One of the most important applications of malleable iron is for the manufacture of toothed wheels for machinery, but the process cannot be relied on to produce a really tough metal when the castings are very large, or have any considerable portions exceeding 2 in. in thickness. Certain qualities of cast iron may be rendered stronger and tougher by the addition, in the cupola, of a proportion of wrought iron, steel, or manganese; this metal is said to be better adapted for spur-wheels than common cast iron.

The general routine of the process of making malleable castings is as follows:—The pig iron is melted in and run from clay crucibles into green or dry sand moulds, and where the articles are small, snap flasks are much used. The castings are removed from the moulds, and cleared from sand by brushing, by shaking in a rattle-barrel, or by similar means, and are then placed in cast-iron saggers, with alternate layers of powdered red hæmatite ore, or with fine iron scales from the rolling mills. The saggers are then placed in the annealing furnace, where they are exposed to a gradually increasing degree of heat, until a full red heat is attained, after which they are allowed to cool down. The articles are then removed from the saggers, cleaned from the hæmatite powder, and so far as rendering them "malleable" is concerned, the process is completed.

The pig iron employed is almost invariably hæmatite; for large castings white hæmatite pig is selected, for small articles mottled pig. In England, Cumberland iron and irons from the Barrow

Steel and Iron Company's Works are largely employed; while in America they prefer the best brands of cold-blast charcoal mottled irons, Nos. 4 and 5 Baltimore, or 5 and 6 Chicago, having an excellent reputation.

It is essential that the pig shall be white or mottled, not grey, and it is not uncommon to melt up a quantity of scrap, such as wasters, gates, and fins of white iron.

The clay crucibles in which the iron is melted are frequently made in the foundry; they are heated in several ways. In the case of large works, the gas regenerative furnace is the most economical apparatus for melting in the crucibles, with which any desirable temperature can be obtained and regulated.

When the articles to be cast are of greater weight than, say, half a hundredweight, the pig is occasionally melted by coke in a small cupola, with fan-blast.

But the most usual form of furnace for ordinary work is the common air-furnace, with the grate and ash-pit below the crucible.

In making the moulds for small articles in malleable iron, the runners are nearly always formed in the parting of the box, and both gates and runners are made as small as possible; flat, wide, and thin in cross-section. This is rendered necessary from the rapidity with which the metal cools, causing it to contract, and frequently to break off from the gates very quickly after the metal is poured.

For small articles it is not usual to face the moulds, as the metal must be poured at such a high temperature that facing would be useless; the small stream of metal, however, is so rapidly cooled in its passage through the mould, that it is not indispensable for the sand to be as infusible as it would be required with larger work.

The amount of contraction appears to be greater with these castings than with soft cast iron; they are very brittle, and should have a white crystalline fracture.

For small work parting sand is not used for the boxes, but fine dry powdered clay; the moulds are generally dried in small stoves, heated by coke, or the waste heat from a crucible furnace. This operation takes but a short time. The castings must be raked, or if very small, sifted, out of the sand when cool, and must then be cleaned from sand, which can be easily effected, if the articles are of a convenient shape, by rolling them over each other in a barrel called a tumbler or rattle-barrel; or they can be cleaned by hand, or immersed in a bath of dilute sulphuric acid, after which they must be washed and dried. Runners or fins on the castings have to be chipped off with the edge of a steel chisel, as they cannot be filed away.

The annealing pots are cylinders, preferably of cast iron, about 12 in. diameter, by 16 in. high, with loose covers dropping in. This size is well adapted for small articles, but for special purposes the pots are frequently made of wrought-iron plates, which, however, will not stand the action of the annealing furnace more than three or four times, whilst the cast-iron pots will frequently serve for twenty annealings.

The material most frequently used for filling in the pots between the tiers of articles to be annealed, is red hæmatite ore, which is ground and sifted through a mesh of about an eighth of an inch, the powder not being used, or if iron scales are employed, care must be exercised to keep them free from dirt.

A certain quantity of fresh hæmatite, or iron scale, should always be added, to any that has before been used, without the latter has been newly ground up.

A layer of hæmatite, or iron scale, is spread over the bottom of the pot; on this the first row of castings are placed, each article perfectly isolated and imbedded in the hæmatite, then another layer of about half an inch of the hæmatite, then another row of castings, and so on until the pot is nearly full, when it is covered up nearly flush with hæmatite, upon which the cover is placed, and the pot is ready for the furnace.

In arranging the pots in the furnace, those which contain the largest work should be placed in the hottest part, and the pots should be marked or numbered, as a guide to the furnaceman as to the amount and duration of the heat to which they should be subjected.

As before mentioned, the duration of the operation depends upon the size of the articles, but the usual plan is to heat the pots gradually to a bright red, at which temperature they must be kept as uniformly as possible from sixty to eighty, or even ninety hours, after which they are allowed to cool down gradually in the furnace for about thirty hours; they are then removed, and allowed to get quite cold before being emptied.

If the castings are removed from the pots before they are cool, they will not have such a good appearance as if allowed to cool in the pots. It is advisable to avoid placing large and small articles in the same pot, as they require to be in the furnace different periods, and the large articles may require to be annealed a second time if this is done.

After the castings have been properly annealed, they are covered with a film of oxide of different colours. These various colours of the oxide are a sign of good malleables. This adherent oxide is removed from the castings by another passage through the rattle-barrel, and the process of malleable iron making is finished.

In every heat or annealing operation, the scales part with some of their oxidizing qualities, and before they are again used they must be pickled and reoxidized. This is done by wetting them with a solution of sal-ammoniac and water, and mixing and drying them until they are thoroughly rusted, when they are again ready for use.

Case-hardening is a means of superficially hardening castings, and is effected by placing the articles that are to be hardened, after being finished, but not polished, into an iron box, between layers of animal charcoal, such as hoofs, horns, leather, or skins, burned and pulverized, taking care that each article is completely enveloped in the charcoal. When the process is conducted on a large scale a proper furnace is used. The materials consist of 90 per cent. of charcoal, the remainder being either carbonate of potash or of lime. The articles are packed in this material in the usual manner, any parts which it is desired to prevent becoming case-hardened, being previously coated with clay. The box is made tight with a lute of equal parts of clay and sand, placed in the fire, and kept at a light red heat for such a time as will give the required depth of case-hardening, which may vary from half an hour to two hours or longer. The articles are then plunged into water, but if they are liable to buckle out of shape, they should be carefully put into the water, end first.

To case-harden cast iron quickly, bring to a red heat, then roll it in a mixture of equal parts of powdered saltpetre, sal-ammoniac, and prussiate of potash. Then plunge it into a bath containing 4 ounces sal-ammoniac and 2 ounces prussiate of potash to each gallon of water.

Another plan is to heat the articles, after polishing, to a bright red, rub the surface over with prussiate of potash, allow them to cool to dull red, and immerse them in water. The following mixtures are also employed in some shops;—(*a*) 3 prussiate of potash to 1 sal-ammoniac; or (*b*) 2 sal-ammoniac, 2 bone-dust, and 1 prussiate of potash.

The length of time the articles are allowed to remain in the furnace varies according to their size and the depth to which the steeling is desired to penetrate. If there are two retorts they can be charged and drawn alternately.

Casting Iron on to other Metals.—It is occasionally desired to unite other metals by means of cast iron, or to fix ornamental castings on to light work, made of wrought iron or steel.

Such a process cannot be practised with cast iron upon any of the other useful metals than cast iron, wrought iron, or steel, as all the other metals, at all commonly used, have melting points so much below that of cast iron, that they would not bear coming in contact with liquid cast iron.

Sometimes non-metallic substances, such as grindstones, are held in shape by rings or bands of iron cast round them.

When iron is cast upon or around solid wrought iron or steel, certain changes are brought about upon these metals. The cast iron, when thus brought into contact with the comparatively cool surface of the solid wrought iron or steel, will of course be "chilled" at and around all points of contact. It will therefore be harder, more brittle, and much less tough in those parts; and this result will occur wherever liquid cast iron comes in contact with either solid cast iron, or wrought iron, or steel.

When wrought iron is employed it is found to undergo a certain amount of deterioration, both in toughness and cohesion, becoming of less value for structural purposes where those qualities are required. Steel suffers in the same manner, but to a much less extent. A bar of cast iron, cast round a core of wrought iron, will be found little, if anything, stronger than a simple bar of cast iron of the same size. Consequently, where the full strength and toughness of these metals are required, casting-on should be avoided, and especially in any work which will be exposed to sudden shocks or varying strains.

But a very large number of useful and ornamental articles, requiring little absolute strength, can be most readily produced by the process of casting-on, such as hand-railings, window frames, panels, hat and umbrella stands, bedsteads, or ornamental gates.

One well-known application of this process is Moline's invention for the combination of wrought and cast iron in the manufacture of window frames. The sash-bars are formed of wrought iron, rolled of any light and convenient section, suited to receive glass; these bars are united by ornamental cast-iron bosses.

An iron pattern is first made, from which a sand mould is obtained, the wrought-iron bars are cut to the required lengths, and placed in the mould, with their ends nearly touching; over these ends the mould of the boss is placed, which must be sufficiently large to cover them, so that when cast on, the bosses shall firmly unite the wrought-iron bars. These windows can be readily made of any usual size or shape, and are easily fixed. They are light in appearance, and combine the strength of wrought iron with the ornamental character which can be easily obtained by the addition of cast-iron flowers, scrolls, armorial bearings, or other ornaments.

For ornamenting wrought-iron railings, two ways of applying cast iron may be mentioned. Either the wrought-iron bars may be placed in the moulds, and the ornaments cast round their ends, or the ornaments may be cast in green-sand moulds, cored out to fit the wrought-iron bars, on to which they are afterwards fixed by an alloy of zinc and lead. Lead alone is to be avoided, as it sets up a galvanic action, and assists the formation of rust.

If cast-iron chill-moulds are used for the ornamental castings, the ornaments will naturally be rather brittle; in most cases this will be found of little consequence, but where it is desired to avoid brittleness, the work can be placed in an annealing oven, when the cast iron will be made into malleable cast iron, without prejudicially affecting the wrought iron, if any is used in conjunction with the cast iron, as is frequently the case.

Burning-on is occasionally practised, for the purpose of ornamenting wrought iron with scrolls, volutes, or twisted forms. Loam moulds are made, and when thoroughly dried, are applied to that portion of the wrought iron which it is wished to burn on to; cast iron is then poured through the moulds until the wrought iron is brought to a welding heat; pouring is then ceased, and the cast iron, when cooled down, is found firmly affixed to the wrought iron.

For ornamental cast-iron railings which are designed with comparatively heavy pilasters and bars, having the intervals between them filled in with light ornamental work, the two should not be cast at one and the same time, otherwise the light work will be almost certain to break away from the heavy, owing to the unequal contraction in cooling. The ornamental work should be cast first, of fine, soft, fluid iron, and be provided with small fitting pieces or lugs, at convenient points for fixing to the heavy bars or uprights.

Coat these lugs on the fine work with clay and blackwash, place it in a sand mould, and cast the heavy work round it. By so doing the iron will not be liable to fracture from unequal contraction and expansion; but brittleness is another danger to apprehend, which shows that very ornamental fine work, which is usually costly, should be avoided in all public thoroughfares.

Burning-on is sometimes of service in repairing a broken or damaged casting, but the process is neither applicable to fine delicate work, nor to cases where the size and shape of the original casting must be strictly preserved, as in a cast-iron wheel, which would probably be twisted out of shape, by the expansion and subsequent contraction of the metal, during the operation of burning-on.

But a piece of machine framing, the necks of rolls, or a standard which has been broken or found defective, may be repaired as follows:—First cut away the defective parts down to the sound metal, build a coke fire round the part of the casting which is to be repaired, until it is brought to a bright red heat, then dust over the surface of the cut metal with powdered glass or borax. Then apply a hollow loam mould of the desired part to the casting, properly secured in position, and provided with a hole for the exit of the metal. Pour very hot liquid cast iron into the mould, and allow it to flow away, until the cut surface of the original metal of the casting can be felt with an iron bar to have become soft and pasty, by contact with the hot liquid iron. Then stop the exit hole, and allow the metal in the mould to set. If the operation has been properly performed, the casting should ring, when struck, with the same sound as a single good casting, thus showing that the old and new metal are perfectly united.

Where portions of large castings require to be removed for this burning-on process, the easiest mode of doing it is, to cut the casting whilst at a cherry-red heat, with a rapidly revolving circular saw, such as is used for cutting off the crop-ends of rolled rails.

Cast iron may also be bent to a considerable extent with safety at a cherry-red heat, which quality is occasionally of service, in remedying variations from the desired shape, arising from contraction in cooling. The bench or surface on which such bending is to be performed must be constructed of non-conducting material, such as baked fireclay, otherwise the iron will part with its heat too suddenly, and break rather than bend.

Holes occasionally occur on the surface of a casting, which, although not of sufficient importance to make it advisable to reject and break up the casting, are unsightly. Liquid cast iron may be poured into such holes, the superfluous metal being removed by an iron straight-edge. It is usually preferred, however, to fill up these cavities with an alloy having a similar appearance to the cast iron, but much more fusible.

CEMENT, CONCRETE, LIMES, AND MORTAR.

Limes.—Lime or protoxide of calcium occurs most frequently in combination with carbonic acid, as carbonate of lime. Carbonate of lime is insoluble in pure water, but if the water contain carbonic acid, bicarbonate of lime is formed. This solution can lose by evaporation half its carbonic acid, when an insoluble carbonate is formed, this action occurring naturally in the formation of stalactites and stalagmites, and in the formation of calc-sinter in so-called petrifying waters. This action may take place when lime is used in certain cements. When carbonate of lime is ignited at a white heat, the carbonic acid is disengaged, and protoxide of calcium or caustic lime remains, 100 parts of carbonate of lime yielding 56 parts of burnt lime. Burnt lime is the common commercial form. If carbonate of lime be superheated in a closed space it melts, forming a crystalline clinker of an afterwards unalterable carbonate. In burning, lime undergoes no diminution of volume.

The burning of lime is effected in kilns, in field ovens, and in lime ovens, descriptions of which have been given in this Dictionary.

The quality of the burnt lime of course depends upon the constitution of the limestone burnt. A limestone containing a high percentage of pure carbonate of lime yields a fat lime. Limestone of similar constitution to dolomite, containing magnesia, yields a poor lime, which forms only a thin pulp with water. 10 per cent. of magnesia renders the lime appreciably poor, and 30 per cent. causes the lime to be useless.

Burnt lime so easily slakes with water that 100 parts of lime require only 32 parts of water, or 3 volumes of lime to 1 volume of water, the combination attaining a temperature of 150° C. The result of the slaking is lime meal or powder lime, a hydrate of protoxide of calcium, which exceeds in volume three times that of the lime slaked. If less water is added than is requisite for the formation of the hydrate, there results a sand-like powder of no technical value. For this reason, lime should not be placed in baskets exposed to moisture. For building, the lime is slaked with one-third its weight of water, and an equal quantity of water is added to form a thin pulp, or cream of lime.

Cream of lime mixed with sand forms mortar, which may be either air-setting or hydraulic mortar. Limestone containing more than 10 per cent. of silica, when burnt and made into a mortar, hardens under water.

W. Mead converts lime that has been used in the purification of illuminating gas into caustic lime. The spent lime is pressed into bricks or blocks by the same means as are employed for forming ordinary bricks. These bricks are placed in a convenient kiln, and subjected to increasing heat sufficient to drive off the moisture, ammonia, carbonic acid, and sulphur which the lime has absorbed in purifying the gas.

The difficulty experienced in reburning lime of this character has arisen from its powdery nature, by which the permeating of the mass by the flame is prevented. By pressing the lime into bricks this difficulty is avoided. The lime is taken as delivered from the purifying boxes, and is pressed. Fire is now started in the fire-box, and the bricks are burned in the same manner as clay bricks. The length of time necessary to drive off the moisture, ammonia, carbonic acid, and sulphur depends somewhat upon the size of the kiln and the intensity of the heat.

The bricks will shrink in size as they lose carbonic acid, sulphur, and the like, and from such shrinkage it can be ascertained when the burning is finished; from 20 to 36 hours are sufficient. By this process the lime may be used an indefinite number of times, as by each burning it is converted into caustic lime, only requiring slaking to convert it into the hydrate and fit it for the purifying boxes again, or for other purposes for which caustic lime is used.

D. Michel manufactures hydraulic limes and cements by subjecting the raw materials to a special treatment with acids.

Instead of keeping the heat of the kiln in which the materials are calcined within certain limits, it is raised so as to over-burn the products. The first lime, which is in excess, is extracted, and the nodules then subjected, as well as the under-burnt remainder, to the action of a bath of dilute hydrochloric acid. The proportion of acid will of course vary with the amount of lime contained in the under-burnt portion and nodules, but it should not exceed on an average 3 or 4 per cent. The proportion should, in all cases, be determined with accuracy by a preliminary test and a previous analysis of the raw materials. The nodules and under-burnt portion are allowed to effervesce in the acid baths until quite cool, and are then dried in a furnace until fit for grinding in the ordinary manner.

Hydraulic cements and limes may therefore be over-burnt without injury, the under-burnt portion and nodules, which in the ordinary process of manufacture are wasted and cause considerable loss, being utilized for the manufacture of hydraulic limes and cements of first quality.

Mortar.—Slaked lime exposed to the atmosphere absorbs carbonic acid, shrinks, cracks, and when perfectly dry is of the hardness of marble. On account of the shrinkage it is necessary, in order to form mortar, to add sand or some similar material. Angular or sharp sand makes a tenacious mortar, whilst round-grained sand yields a brittle mortar. The proportion of sand to lime depends upon the nature of both materials.

The drying out of the water from mortar is not the only cause of hardening, as may be readily learned by drying mortar by artificial heat. The setting has been accounted for by supposing the formation of neutral carbonate of lime, which does not convert to ordinary carbonate. But this theory does not agree with the results of analysis, as 20 to 70 per cent. of carbonic acid has been found in mortars. No theory covering the ground fully has yet been advanced.

Mortar formed with hydraulic lime is termed hydraulic mortar; hydraulic lime is a mixture of carbonate of lime with silica or a silicate, generally silicate of alumina. During burning, hydraulic lime undergoes a change similar to that which occurs when a silicate insoluble in acid is precipitated, while applying heat, by an alkaline carbonate. Hydraulic mortars are composed with a thin pulp of lime, to which sand is added, or by mixing air-setting mortar with cement.

In some experiments carried out at Bangalore, India, by E. Nicholson, the bricks, although of good quality, were often unable to bear a strain sufficient to rupture the mortar. With 17 to 22 lb. a square inch the bricks showed a tendency to peel. In the course of the experiments, it was found that the adhesive strength of the best cement was invariably greater to stone than to bricks, in the average proportion of 1·7 to 1. In using mortars consisting of sand and fat lime, in the proportions of 1 shell lime paste, 2 sand, the best results were obtained when the bricks were soaked for a few seconds only. In mortars of fat lime and soorkee, or pounded brick, the adhesive strength decreases with an addition of soorkee beyond 1 part, but diminishes still more rapidly when diluted with sand, while for tensile strength the proportion of soorkee is unimportant, the cement being as strong with sand as without. The best soorkee cement for masonry is made with 1 of soorkee to 1 of lime paste or an equivalent quantity of slaked lime; after twenty-eight days' immersion it is of greater strength than the best bricks, and withstands a disruptive force of 60 lb. a square inch. When rapid setting is an object, the proportion of soorkee may be increased to 2 parts, but with some loss of strength. For economy the former cement may be diluted with 1½ of sand; and with rubble masonry, 2 of soorkee may be used with 1 of lime paste, and the cement diluted with 2½ of sand.

Cement.—Cement, or artificial hydraulic mortar, can be prepared from ordinary lime by adding silica. There exist natural cements prepared from tuff-stone, or trass, a tertiary earth, having for base pumice-stone; Italian pozzolano and santorin are the chief of these cements, but the use is very limited.

The hardening or setting of hydraulic mortars has been studied by many eminent chemists, but the hypotheses advanced are unsatisfactory. Portland cement is considered, by Winkler and Feichtinger, to harden from the chemical action, effected with the aid of water, under which the silicates separate into free lime and into combinations between the silica and the calcium, the alumina and the calcium, the separated lime combining with the carbonic acid to form carbonate of lime. In Portland cement the silicic acid can be represented by alumina and oxide of iron. Winkler concludes that in all hydraulic mortars the hardening depends upon the chemical combination between the lime and the silica, as well as between lime and the silicates contained in the cement, and these views are undoubtedly correct, although not definitely proved.

Fuchs, of Munich, explains by the following theory the reactions occurring in the manufacture of cement as practised in Germany. The carbonate of lime becomes caustic on burning, and acts upon the clay in such a manner that the silicic acid is set free by means of the caustic lime, and combines with the lime upon subsequent treatment with water, producing a hydro-silicate, the presence of alkalies by their substitution through heat favouring the reaction. Cement is stated by other German authorities to owe its quality of hardening to the presence of silicates and aluminates of lime formed by the action of heat.

Portland Cement.—There are at present two different methods of manufacturing it. According to the wet method commonly practised in England, the chalk and clay are first washed in wash mills with harrow tines, and are mixed with about five times their weight of water. They are thus thoroughly disintegrated, and the mixture flows out of the wash mills as a liquid of about the consistency of milk. The next process of manufacture is the separation of the water which has thus been mixed with the chalk and clay, in order that the slip or slurry, as the mixture is termed, may be sufficiently dried for burning in kilns. The liquid is therefore run into reservoirs, or backs, in which the chalk and clay gradually subside, and the water above is removed by drainage and by evaporation. This process occupies from six to twelve weeks.

According to the dry method, as practised in Germany, the chalk and clay are each ground separately, having been first artificially dried to facilitate the grinding. They are then mixed, and the mixture resulting is made into bricks or lumps by the aid of just sufficient water to bind it. The bricks are then burnt in kilns with or without being previously dried.

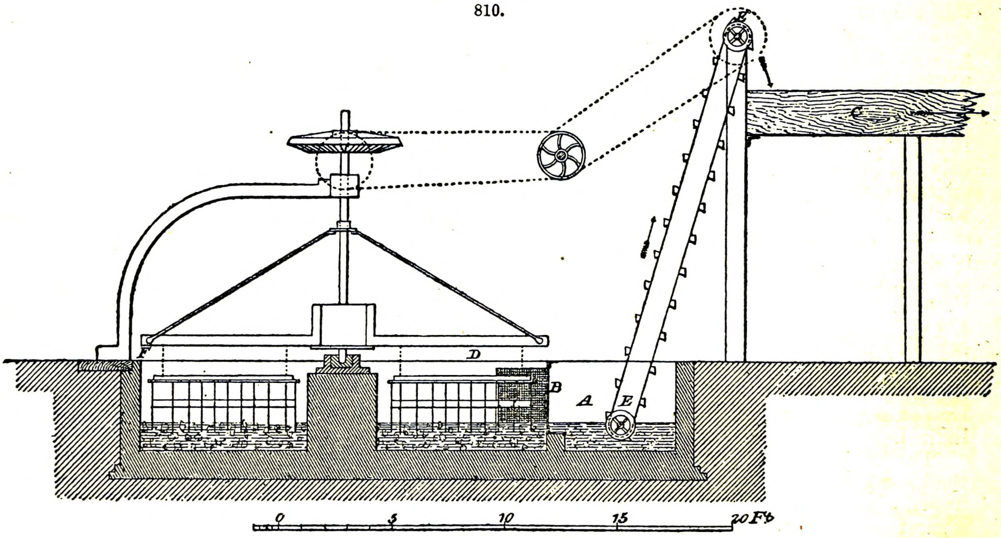
According to Goreham's process the chalk and clay are roughly mixed in a wash mill with a small quantity of water only, say from one-fifth to one-third of the total weight. The product resulting from this operation is not a liquid, but a mud with coarse particles of undisintegrated chalk and clay interspersed throughout it. This mud is then passed through a pair of millstones, such as are used for grinding cement after it comes from the kilns, and thoroughly comminuted and mixed. It is then immediately transferred to the drying stoves or chambers, without being poured into the reservoirs or backs, and the dried slip is burnt in kilns. A portion of the fuel for burning the cement may be mixed with the chalk and clay, and in such case the fuel is added to the other materials in the wash mill.

By this process the time, space, and expense is avoided, involved in driving off the excessive quantity of water with which the chalk and clay are mixed according to the wet way of manufacture, by effecting the perfect disintegration and mixing of the materials with a small quantity of water only, and obtaining a product which can at once be dried by artificial means without the aid of drainage or evaporation in backs. The expense incurred in the dry process is avoided by drying and grinding the chalk and clay separately, and in afterwards mixing them with water, and finer comminution and more uniform admixture can be obtained.

The chemical analysis of Portland cement gives about 80 per cent. of carbonate of lime, the remaining 20 per cent. being composed of silica, iron, and alumina. In practice these proportions are roughly attained by a mixture of limestone and clay, of about 4 of chalk to 1 of clay, according to the ingredients each material used is found to contain. These are mixed in what are known as wash mills.

The wash mill, Fig. 810, is a circular pan about 18 ft. diameter and 4 ft. deep, usually built of brick, with a brick bottom, sunk into the ground and puddled on the outside. On one side of the pan is an opening, or in some cases an overflow; in the case of an opening this is covered with perforated zinc or wire gauze, forming a sieve, so as to allow of nothing passing but the chalk and clay which are held in solution. In the centre of the pan is a revolving vertical shaft, to which is bolted a framework carrying the harrows; these have their tines fixed at different distances from the centre, care being taken to arrange them so that no two shall immediately follow each other in their course, or in other words, be the same distance from the centre. The tines are usually made of wrought iron, about 1¼ in. square, and their distance apart must vary according to the size of the chalk to be washed, chalk in large pieces of course requiring the tines to be placed farther apart than when small refuse chalk is used. The centre shaft, being driven at about 18 revolutions a minute, by means of bevel wheels fixed on the top, and connected to the engine by a driving strap, takes the harrows round, and thus mixes or washes the chalk and mud. Some manufacturers prefer to have the gearing arranged underneath, in order to allow of a perfectly open space over the pan; but in that arrangement the difficulty of getting at it for oiling, and the quantity of dirt which works into the bearings, quite obviate any advantage gained by a clear space above, as the overhead gearing, if properly arranged, need in no way interfere with the workmen. Outside the pan is the well A, into which the washed clay and chalk run through the sieve B. If two or more wash mills are used, it is advisable to connect them all to one well, so that one pump may lift all the slurry from the different mills up to the trough C, leading to the backs. One of the difficulties attending this part of the manufacture of Portland cement is the continued choking of the pump; an elevator is therefore used. It is simply a succession of buckets fixed upon a continuous band, revolving round an upper and a lower drum, as at E E; the buckets dip into the well A as they come to the lower drum, and take up the slurry, which, as they turn over at the top drum, is thrown into the leading trough C. The size and number of the buckets depend on the quantity of slurry to be lifted an hour.

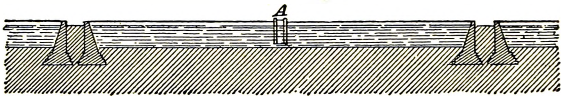
810.

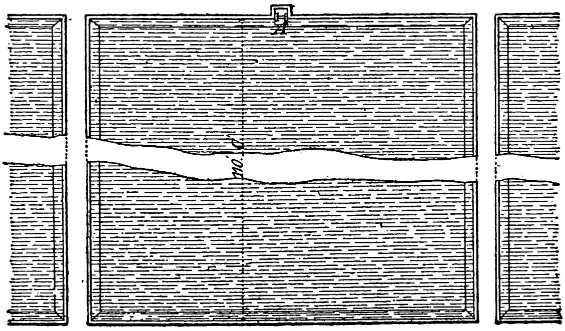


The process of washing or mixing is simple; the chalk and clay, measured by the barrow load, are tipped into the pan at the point D, Fig. 810, and the water is admitted at the point F, in the proportion of about 2 of water to 1 of chalk and clay. The tines in their revolution throw the chalk and clay about, and thereby thoroughly mix and disintegrate them; and being thus held in solution, the material passes through the sieve or over the overflow, as the case may be, into the well A, in the form of slurry, which is then lifted by the elevator or pump to the leading trough C, and thence passes to the back.

The backs are reservoirs usually made large enough to contain about 600 cub. yds. of slurry; thus, as 2 cub. yds. of slurry yield about 1 yd. of finished cement, and a back will take from six to eight weeks to settle, it is easy to determine the number required, the depth being about 4 ft. and the sides built sloping, as in Figs. 811 and 812. It is advisable to have as much back room as possible, in proportion to the rest of the works, as, although the mills may be worked day and night, the slurry can only settle by gradual subsidence; and pushing a back, that is, putting the slurry on the drying floor too wet, necessitates a greater amount of fuel to dry it, and thus a loss. When a back is filled it is allowed to settle, the chalk and clay sinking to the bottom. The water is then drawn off by means of the sluice at A, and the back is refilled, the water being again drawn off when it is settled, and so on until the back is full; the slurry is then dug out, and laid on the drying floor.

811.





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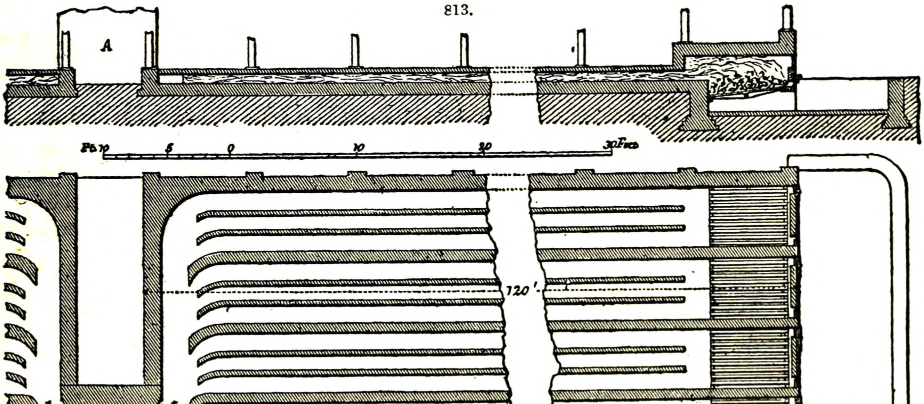
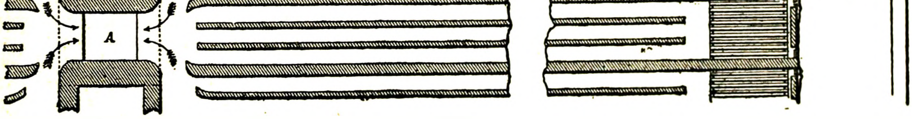


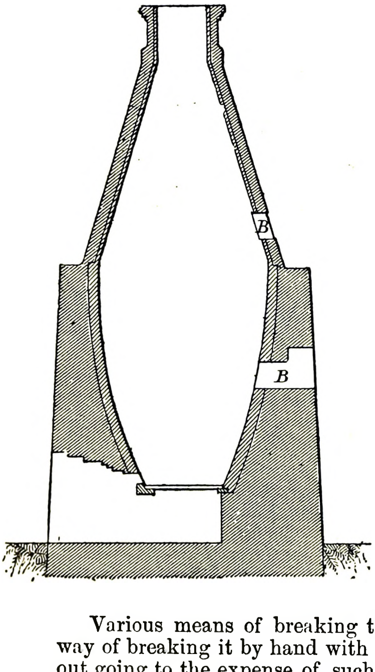


814.

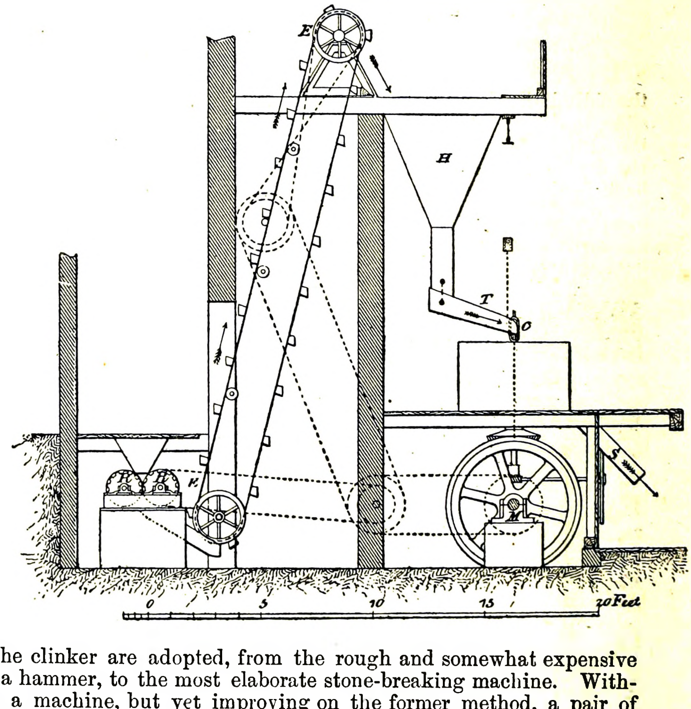
The drying floor, Figs. 813 and 814, is formed of fireclay tiles on iron plates, with an arrangement of flues underneath, stoked at one end, and meeting a cross flue at the other end conducting to the chimney shaft A. In most cement manufactories the drying floor is constructed with coking ovens underneath, so that, while drying the slurry, coke to be used in the kilns is manufactured; but a simple firegrate is preferable. With that arrangement the cheapest fuel can be used, less care is required in stoking, and the loss from bad coke is avoided; the cost of construction is considerably reduced; besides which, the repairs needed to a coking oven are considerable, as against almost none in the other case. It is advisable to construct the floor of such a size as to dry sufficient slurry for one day's work, so as to avoid loss of labour and fuel; it should be covered with a light roof supported on columns, the sides being left open to allow the moisture evaporated from the wet slurry to escape, but at the same time protecting the floor from the weather. The slurry, as it is brought from the backs, is laid on the drying-floor in a layer about 5 in. thick, which by the evaporation of the moisture becomes reduced to about 4 in. when dried; it is then ready to be loaded into the kilns to be burnt.

The kilns are circular in plan, and usually of about the form Fig. 815; but the shape varies considerably in different districts. The principal requirements are that they should have a good draught, and that their inner surface should be so formed that the clinker as burnt shall fall to the bottom evenly and without clinging to the sides; for when the clinker hangs, its weight necessarily brings down some of the inner casing of the kiln, and the kilns, under the most favourable circumstances, form one of the most expensive items in a Portland cement manufactory, costing as much as from 30 to 40 per cent. a year of their first cost to keep them in repair. Perhaps the most economical size of kiln to adopt is one large enough to burn from 20 to 30 tons of finished cement. For a 20-ton. kiln a capacity of about 70 cub. yds. is requisite, though many manufacturers, by what is called topping, that is, adding fresh coke and dried slurry as the clinker sinks, burn 30 tons in a kiln of that size. As a kiln takes one day to load, one day to burn, one day to cool, and one day to unload, the number of kilns required for four days' work, is four times the number required for one day's burning; but as repairs are always necessary, it is well to provide a sufficient number of kilns to do from four and a half to five days' work. The kilns are charged through the loading holes at the points B B, Fig. 815, with alternate layers of coke and dried slurry, in the proportion of one of coke to two of dried slurry; and when properly burnt the kiln is opened and allowed to cool, and as the clinker is drawn it is taken to the crusher to be broken into pieces about 1 in. cube, preparatory to being passed through the millstones. The kiln is drawn by knocking out the firebars, and the charge falling into the ash-pit is taken out and carried to the crusher.

815.



816.



Various means of breaking the clinker are adopted, from the rough and somewhat expensive way of breaking it by hand with a hammer, to the most elaborate stone-breaking machine. Without going to the expense of such a machine, but yet improving on the former method, a pair of crushing rollers, as shown at R R, Fig. 816, may be adopted with economy. The rollers, made of cast iron with chilled faces, are formed with grooves along their entire length, and are placed at such a distance apart as to break the clinker to the requisite size. A hopper is placed over them, leading the clinker between the rollers, which, by revolving in opposite directions, crush it as it falls between; the clinker is then led by an inclined plane into a trough, to be lifted by the elevator E into the hopper H, supplying the millstones. The elevator is on the same principle as that for lifting the slurry; but the buckets are considerably heavier and stronger, and should be lipped with steel in order to withstand the roughness of the broken clinker.

The hopper H, Fig. 816, leading to the millstones, should be made with the sides sloped to a sufficiently steep angle to allow of the clinker falling easily to the bottom and into the shaking-trough T. This trough, which is made to shake by means of a cam C fixed on the centre shaft of the millstones, allows the clinker to fall gently in between the stones, and the shaking prevents the clinker from blocking the lower mouth of the hopper.

The millstones, generally from 4 ft. to 4 ft. 6 in. diameter, have an outer casing of iron. The clinker falling into the centre of the top stone is taken in between the stones, and is gradually ground, and led to the outer edge by grooves, such as are usually cut in millstones; it thence falls into the outer iron casing, from which a spout S leads it to any convenient place where it can be collected in barrows, and laid on the warehouse floor.

It is found convenient to drive the millstones, crusher, and clinker elevator by one engine, driving the mill shaft by means of friction or toothed wheels direct from the main shaft M of the engine; this is placed under the herse floor, which should be about 6 ft. above the warehouse floor. By this arrangement any number of stones may be driven, by connecting them to the shaft by bevel wheels; the bearings are all covered up, and the dust from the cement is kept from them. A good inclination can be given to the spout S, leading from the millstones, thus enabling the ground cement to clear them easily. The elevator and crusher may be driven from the mill shaft or from the main shaft of the engine as found most convenient. Each millstone requires from 8 to 10 horse-power to drive it; the power to drive the elevator and crusher must of course depend on the amount of work which they have to do, but it may be allowed that for a four-stone mill about 40 horse-power will be required to drive the stones, elevator, and crusher. It is preferred by Faija, whenever possible, to drive the wash mills and slurry elevator by separate power from the rest of the machinery, because, besides the advisability of sometimes placing them at some distance from the mill and warehouse, it is always well to be able to continue filling the backs, even when the rest of the works are temporarily stopped. The power required to drive a wash mill of the construction shown in Fig. 810, with its elevator, would be from 8 to 10 horse-power, and it would wash from 80 to 90 tons of slurry a day.

As the wash mill is where the ingredients ultimately formed into cement are first incorporated, it is of the greatest importance that the proper proportions of chalk and clay should be used, and it is therefore imperative that frequent trials should be made of the slurry as it leaves the wash mill, so as to ensure the backs being filled with a uniform quality. The chalk and clay should also be occasionally analysed, in order to correct any variations that may occur in either.

The drying process being merely an intermediate stage, assisting in abstracting the moisture from the slurry, does not call for particular attention; but the kilns need careful manipulation. Care must be taken that the kiln is burnt evenly throughout, and when unloading, the clinkers should be carefully sorted, and all yellow or softly burnt pieces returned to be placed on the top of the next kiln and reburnt; and only that clinker which is perfectly burnt should be passed to the crusher to be prepared for grinding.

Having passed through the millstones, the ground cement is laid out on the warehouse floor and allowed to cool, being occasionally turned over. This mixes the different days' work and gives uniformity to the cement produced, and also allows any particles of lime still unslaked to slake by exposure to the air. The cement should be left in this way for a considerable time before being packed, and it will then have become thoroughly cooled, and there will be but little fear of its blowing when used; curiously enough it will also have increased in weight and bulk, so that it is to the advantage of the manufacturer to follow this course, though the great demand for cement, the space it occupies, and other trade reasons, often prevent this plan being carried out.

The quality of Portland cement is usually determined by its colour and its weight, in combination with its fineness; besides which it is required to withstand a certain tensile strain when made into a briquette, or small testing block, and to show no signs of either expansion or contraction in setting. Though at present considerable diversity of opinion exists as to what the tests for fineness and tensile strength should be, still, when it is remembered that the cement should be of one uniform good quality, capable of being gauged with two or three or even more times its bulk of sand for use, and that when the weight and fineness are in such proportions as to give a good carrying capacity for sand, the tensile strength is assured, it becomes possible to arrange such tests as will meet most requirements.

In colour Portland cement should be of a dull bluish grey, and should have a clean, sharp, almost floury feel in the hand; a coarse, gritty feel denotes coarse grinding, and the finer a cement is ground the more it approaches to an impalpable powder. It should weigh from 112 lb. to 118 lb. a striked bushel, and should be so fine that 80 per cent. will pass through a sieve of 2500 meshes to the square inch; when moulded into a briquette and placed in water for seven days, it should be capable of resisting a tensile strain of from 300 lb. to 400 lb. a square inch, and should, during the process of setting, show neither expansion nor contraction.

A light cement, one weighing from 100 lb. to 108 lb. a bushel, is invariably a weak one, though it may be of requisite fineness; at the same time a heavy cement, if coarsely ground, is also weak, and will have no carrying capacity for sand. As the more the clinker is burnt the harder and heavier it becomes, and therefore the more difficult to grind in the millstones, the heavy cements are almost invariably coarse ones, and as an under-burnt cement from its softness will be ground fine enough, but will be deficient in weight, it will be seen that the weight, unless taken in conjunction with the fineness, is no test as to the quality of the cement. It will therefore be found advisable to adopt a medium weight such as already mentioned, namely, from 112 lb. to 118 lb. a striked bushel.

Expansion, which is due to the cement being too hot, is met with most frequently in very heavy cements, from their containing in their original crude form a large proportion of lime, which does not get thoroughly removed in the process of burning in the kilns; small particles consequently remain unslaked, which slake when the cement is gauged with the water for use, and these eventually blow in the work, causing a general expansion. An under-burnt cement, or one that is used too soon after it has left the mill and before it has had time to cool, will show the same defect. The most simple test for detecting expansion in a cement, is to make small pats with a trowel, about 3 or 4 in. square, and place them in water when set sufficiently, where they should remain a few days. If the cement be good, they will show no alteration in form, but any cracks showing on the edges, or other deviations from the original shape of the pats, indicate that the cement is of this expansive nature, and therefore not to be trusted. But because a cement will not stand this test, it is not in all cases to be condemned as useless, as its expansive or blowing property may be attributable to its being used too soon after leaving the mill; a proper process of cooling, placing it in a thin layer on a dry floor for a short time before using it, will correct the defect.

Contraction, due to the cement being over-clayed, may be detected by a similar test to that for expansion.

J. B. White and A. Glover have effected improvements in the manufacture of Portland cement, relating to the drying and burning of the wet slip or slurry from which the cement is produced.

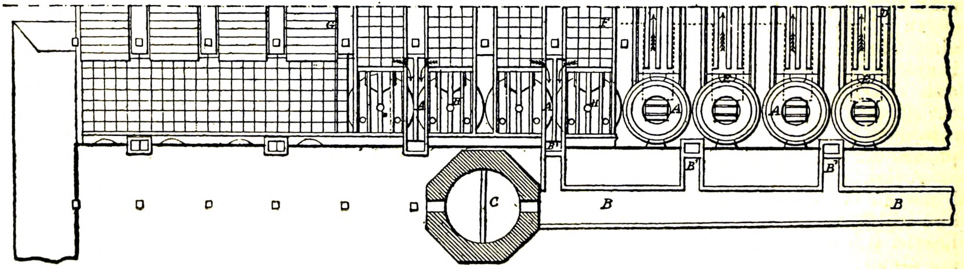
For this purpose kilns of smaller dimensions than is usual are employed, covered at the top with an arched dome, through which is an opening for charging the materials into the kiln, and also other openings for allowing the heated gases from the kiln to pass into a flue or drying chamber on the ground level. The chamber may be divided by a horizontal partition of tiles, on to the top of which slip or slurry, containing, say, about 40 per cent. of water, as prepared by the Goreham process, can be pumped. A further quantity of the slip or slurry is also pumped on to the top of the chamber, which consists of iron plates.

The heated gases as they come from the kiln are caused to pass along the chamber on the under side of the horizontal partition, and at the end of the chamber to rise up to the top of the chamber and pass back above the partition, and are afterwards led away by side openings to a flue leading to a chimney. By this construction of kiln and drying flue the heat of the gases evolved in the burning of a charge in the kiln is utilized, and without using more than the minimum quantity of fuel necessary for the proper calcination of the Portland cement; the heat given off is more than sufficient to dry the quantity of slurry required for the next charge and burning off of the kiln. The size of the kiln, about 11 ft. deep and 10 ft. diameter at top, allows of its being charged or loaded from the loading eye or opening at the top, instead of, as is usually the case, requiring men to descend into the kiln to load it. The advantage of this is absence of delay, which enables a much larger quantity of cement to be got out of this size kiln weekly than is usual. The burnt cement is drawn off from the bottom of the kiln.

Instead of the drying flue being divided by a horizontal partition, it may be formed without this partition, and slip or slurry be pumped on to the top only of the flue; in this case, vertical partitions are used to cause the gases to travel to the end of the flue, along one of its sides, and then back on the opposite side.

In Figs. 817 and 818, A A are the kilns arranged in two parallel rows, with a flue B between them, leading to a chimney C; one row only of the kilns is shown, the other row is ranged in the same way on the opposite side of the flue. D D are the drying flues, one for each kiln. The flues are similar in their construction to flues used for drying slurry. The gases from the kiln enter the flue through openings E, and pass along under the horizontal floor F, which divides the flue horizontally, and at the end of the flue they rise up and pass back over the top of the slurry, which is on the floor F, and descend by flues B¹ to the main flue B, entering the chimney at a temperature of about 200° and carrying with them the steam evolved in drying the slurry. The tops of the flues D are covered with plates G, upon which slurry can also be pumped. Each kiln is charged through an opening H at the top, closed whilst the kiln is being fired. Each kiln is circular in plan, having a chamber of about 10 ft. diameter at its upper part, and of a depth, from furnace bars to the loading eye H, of about 11 ft. The top of the kiln is covered by a semicircular dome, which is entirely below the closed top of the drying flue.

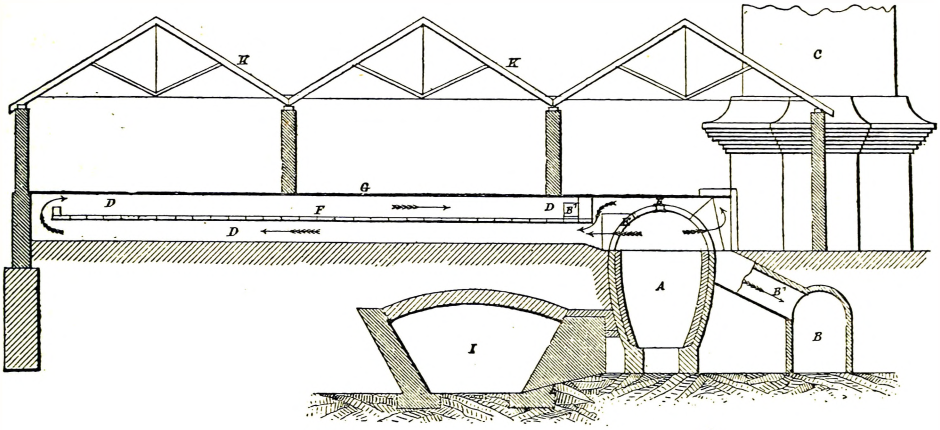
817.



When a charge has been burnt in one of the kilns, it is withdrawn at the bottom into a tunnel I, through which it can be conveyed away.

Amongst the advantages derived from the use of kilns and drying flues arranged in this manner, it is possible to throw in the dried stuff that has to be burnt without injury to the material by breaking, and to avoid the necessity of men entering the kiln and stirring it by hand, requisite with the larger and deeper kilns ordinarily employed to avoid breakage, and also of the kilns being rapidly charged and drawn. The kilns being built close together with an opening only for charging and one for drawing, neither the kiln nor the chamber with which it is connected ever get really cold. This peculiarity, joined to the underground construction, which prevents all leakage and absorbs the whole of the burnt products, permits the kiln to be charged and drawn twice in each week, and consequently to yield weekly as large a quantity of clinker as is usually obtained in that space of time from a kiln of double the cubic capacity. A considerable diminution in wear and tear of the kiln is also obtained consequent on its not being allowed to cool down, and to undergo the alternate contraction and expansion which results from such cooling.

818.



W. S. Akerman manufactures an hydraulic cement from lump and ground blue lias lime. Shales and limestones are carefully selected with a view to their containing in the aggregate, after preliminary calcination, the proportions of lime, alumina, and silica usually employed in the manufacture of Portland cement, and such shales and limestones as do not vary widely from such proportions are preferred. The limestones and shales are then burnt, either separately or together, in ordinary lime-kilns to the inferior limit of calcination, and the burnt product ground between ordinary millstones to a fine powder, care being taken that the burnt products are thoroughly mixed, either before or during the grinding operation. The powder produced is allowed to absorb as much water as it will, no mixing while in a wet state being necessary, and after the hydration is completed, it immediately commences to set, and in a very few days becomes perfectly hard and dry without the aid of artificial heat. The product is again burnt, this time to the superior limit of calcination, and ground, and is then fit for use as hydraulic cement. In the matter of plant, no wash mills or mortar mills, hot plates or drying sheds, or reservoirs are required.

R. O. White and J. B. White have reduced considerably the cost of manufacture of Portland cement. Chalk and clay in the natural state are taken, and without water, an intimate admixture obtained, by placing them together in a hopper, from which they pass to a series of pairs of crushing rollers. The materials as they leave the hopper have first to pass through a pair or pairs of fluted crushing rollers, to other pairs of plain rollers placed closer and closer together, and running at increased surface speeds. By this means the materials are reduced to a thin sheet, the chalk to a thoroughly disintegrated state, and mixed with the clay. After the materials have thus been crushed and mixed together by means of rollers, they are moulded into bricks to be burnt in any ordinary manner, no fuel being mixed up with the materials of which the cement is composed. A convenient arrangement is as follows;—At the top of the machine is a hopper into which is fed chalk and clay, in proper proportions, and in the raw state in which they are obtained. The materials descend from the hopper to a pair of horizontal rollers fluted longitudinally. These rollers are about 12 in. in diameter at the point of the flutes, and are adjusted to work at 13 in. apart from centre to centre, and to make about 10½ revolutions a minute. From these rollers the materials descend to a second pair of fluted rollers of about the same diameter, placed closer together, say, about 11½ in. from centre to centre, and making about 24 revolutions a minute. From these, the materials drop to a pair of smooth rollers, about 1 ft. 3 in. in diameter, $\frac{3}{16}$ in. apart, and making 39 revolutions a minute; from these again to another pair of rollers placed still closer together, say about $\frac{3}{32}$ in. apart, 1 ft. 9 in. in diameter, and driven at about 58 revolutions per minute. All these rollers are 3 ft. long. From the last rollers the materials drop to another pair placed still closer, say about $\frac{1}{32}$ in. apart, 2 ft. 3 in. in diameter, and driven at still greater surface speed, or 88 revolutions per minute; they are also set at right angles to the other rollers, and are 4 ft. 6 in. long. The stream of materials descending on to these rollers from the rollers above them becomes doubled or gathered together, and is intimately mixed. A very perfect mixing of the materials may be obtained even if the last pair of rollers are placed in a line with the other rollers, and not at right angles to them. A scraper, is by means of a weight or spring, held up to the under side of each of the several rollers to prevent the material being carried round with them, and at the ends of the spaces between the several pairs of rollers there are end plates which prevent the material from escaping, and compel it to pass downwards between the rollers. The several rollers are geared together by toothed wheels at their ends, so that they shall revolve together at the required speeds, and are driven by a belt wheel on the axis of one of the rollers. The lowest pair of rollers are driven by a separate belt and belt wheel, or ordinary gearing. The materials having thus been mixed together in the machine, are afterwards moulded into bricks or blocks to be burnt. For this purpose the materials are fed by rollers into a box, across the bottom of which a series of moulds, formed in a revolving table, are caused to pass in succession; the moulds are filled as they pass below the filling box, and are emptied after passing beyond the box. All that is required is that the machine should perform its work quickly, no perfect moulding of the bricks being required; they should be of about the same size, and hold together sufficiently to allow of their being stacked in a kiln.

By this process of making cement the ordinary addition of water to the materials is entirely dispensed with, and consequently the tedious and costly processes of draining and driving off the water, which has been so added, are done away with.

The bricks or blocks as they come from the moulding machinery are, without the intervention of any drying stove process, at once placed in the chambers of a Hoffman's kiln.

T. Hyatt takes Portland cement, and mixes with it sulphur, either in the form of flowers of sulphur, or as combined with iron as iron pyrites, which imparts to the hydraulic cement a toughness or power of cohesion when subjected to the combined action of fire and water.

The sulphur is mixed with the hydraulic cement after the usual manufacturing process is completed, or incorporated previous to calcination, but it is found more convenient in practice, when using flowers of sulphur to make the addition after the cement is manufactured. If the sulphur is employed in the form of pyrites, it is immaterial at what stage of the manufacture it is added.

The sulphur is in the proportion of about 1 part by weight of the sulphur to 10 or 12 parts by weight of the other dry materials.

Cement Water-pipes.—To manufacture water-pipes from cement, as practised in Germany, equal quantities of cement and of hydraulic sand are mixed with the necessary amount of water, and this mixture is poured into the pipe moulds, the sand being previously washed and well mixed with the lime. The interior of the mould is rubbed smooth with dry graphite powder and a linen rag, an operation requiring about twenty minutes' labour for each mould. The core is then inserted, the cement poured in from the mixing mill, and pressed down with a wooden rammer. For a 4 in. pipe, 3½ ft. length, 1 cb. ft. or 58 lb. of lime and 1 cb. ft. or 100 lb. of washed sand are used. After the mould has been filled, its screws are tightened, to ensure that the cement is equally compressed throughout. The exterior of the pipe is octagonal. The pipes require two to three days to set, but the core may be withdrawn after twelve hours. When set, the exterior mould is removed, and the pipes are conveyed to the drying room. These pipes are cemented to each other by placing the ends together, and surrounding them with a leather mould, into which more lime mixture is poured. With water motor power, these pipes can be very economically constructed, at about one-tenth of the cost of cast-iron pipes. But they can only be employed in a non-shifting soil.

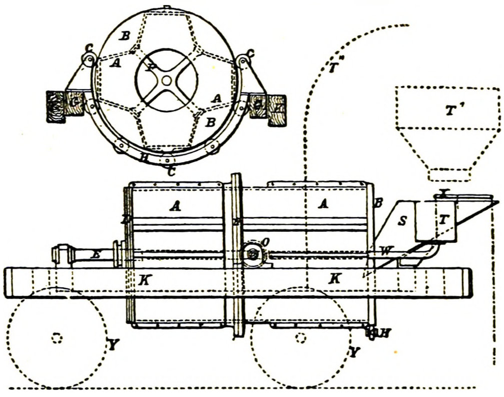
Concrete.—J. Day and W. Lampard mix concrete by the following method. The mixing takes place in a box made in four pieces exactly similar, which when bolted together form a box like a cross; this box is entirely open at one end, and is contracted to a round hole at the other. The open end has a circular cover, which is capable of sliding on the shaft. The mixing box is supported at one end by a shaft attached to a framework at its open end, and working in a bearing on the inner frame. The other end works on a series of rollers carried by the inner frame, and taking two-thirds of the circumference of the mixer, giving it an easy, smooth action.

One of the trunnions carrying the inner frame is driven at one end, and at the other end has a bevel pinion, which gives motion to a bevel wheel on the mixer, causing the mixer to rotate. The other trunnion is fixed at one end to the inner frame, and at the other end is connected to a winch handle, so that by turning the winch handle the mixer is inclined to any desired extent. A water tank is supported on the inner framing, and has a perforated iron pipe passing from the tank through about two-thirds of the length of the box, and there is a valve in the tank for the purpose of admitting water at any desired rate to the box. A hopper is also carried on the inner frame, and is of a shape to allow the mixer to be fed with material either direct or from a hopper suspended from a small davit crane.

When working the machine the material is placed on a stage or platform, measured or weighed in the proper proportions, and if the machine be used without the top or swinging hopper, the material is shovelled direct into the under hopper whilst the machine revolves. The water is admitted at will, and the machine is allowed to revolve sufficiently long to mix the concrete according to the quality desired. The mixing box, as the mixing progresses, may also be rocked or oscillated on the trunnions, to ensure the perfect mixing of the materials. When mixed, the sliding door is opened, and the winch handle turned until the mixture is inclined sufficiently to discharge the contents of the box; then the door is closed, the mixer is placed level, and recharged. The whole operation is performed whilst the mixer is in motion, therefore saving time. The concrete is turned completely over four times in one revolution of the mixer, and by the oscillating motion it is agitated still more in the opposite direction.

In Figs. 819 and 820, A is the mixer or box, the form of the cross section of this box is shown by the dotted lines; B is a disc secured to one end of the box, and resting on rollers C. D is the movable door, capable of being moved to and fro along the shaft E, which is secured to the box by cross pieces F. G is the inner frame, which carries the bearings of this shaft, and a curved frame H, upon which are mounted the friction rollers C. I I are the trunnions, upon which the frame G can swing, and which are supported by the outer frame K. One of the trunnions is made fast to the inner frame, and has upon it a toothed wheel into which gears a pinion turned by a crank handle. On the axis of the pinion is also a ratchet wheel, which can be locked by a pawl, and by this means the inner frame can be set at any angle. N is a bevel wheel around the exterior of the box, and gearing with a pinion O on a spindle P, which passes through the other trunnion, and carries belt wheels for a driving strap. The box or mixer can be revolved continuously, without interfering with its being tilted to any desired angle to discharge its contents, or with its being rocked continuously on its trunnions whilst the mixing is taking place. A lever handle is used for shifting the end door D to and fro along the shaft E. S is a hopper, and T a water tank, both carried by the inner frame G. The hopper S delivers all materials thrown into it, into the box or mixer through the circular opening at the centre of the end disc B. The movable hopper can thus be swung out of the way of the fixed hopper whenever desired, in the direction shown by the dotted line T″. W is a pipe leading from the tank to the interior of the mixer. X is a valve and lever to control the admission of water from the tank to the mixer.

819. 820.



J. S. Wethered, New York, employs a process by which a concrete mixture, composed wholly or partially of furnace slag, limestone, or other calcareous material and asphalt, is prepared.

An excellent concrete is said to be made of 80 parts of furnace slag or limestone, crushed or granulated, and 20 parts of asphalt tempered with mineral oil. The proportion of the oil to the asphalt will depend upon the richness of the latter, but in general should be from 8 to 10 per cent. In order that the furnace slag, limestone, or other calcareous matter, and asphalt may combine completely, and the asphalt be absorbed to the fullest extent practicable, it is necessary to heat the calcareous matter to a high degree after it has been crushed or granulated, and before it is mixed with the heated asphalte. The degree of heat should be more than enough to merely effect the drying of the material. It should be sufficient, not only to drive off all the moisture and carbonic acid which the material contains, but to open the pores, and so expand the material as to enable the heated asphalte to readily permeate the substance, and become thoroughly incorporated with it. But the degree of heat must be within that sufficient to calcine limestone. For heating the calcareous matter, an oven or furnace for roasting ores may be employed.

After the calcareous material has been heated, it is, while in its highly heated state, mixed with the heated asphalt and other ingredients. A horizontal cylinder of iron mounted in bearings, and made to revolve around a shaft with radially projecting arms for mixing the mass, furnishes a simple and effective apparatus for the purpose, and it is advantageous to apply heat to the revolving cylinder while the process of mixing the material is going on. The concrete, so prepared, is in a proper condition to be spread as a side-walk pavement, and rolled smooth.

For paving road beds, it is necessary that prepared concrete material should be condensed under heavy pressure, while in a mould, into the form of blocks. This operation should be performed while the concrete is still hot, as the block is rendered more homogeneous, and the particles composing it more thoroughly compacted. When, however, the block in a highly heated condition is expelled from the mould by the discharging plunger of the compressing machine, it often happens that it will crumble, and to avoid this, time must be allowed for the mass to become set before it is removed. This delay interferes with the economy of the manufacture, and is avoided by subjecting the heated block, after it has been moulded and compressed, to the chilling effect of cold water applied to its surface. This treatment is best performed at the instant that the block is raised out of the mould, or as soon as possible after it has been deposited upon the endless apron or conveyor for removing it from the machine. The effect of this chilling process is to harden the exterior surface of the moulded block, so that it will preserve its form and integrity during subsequent handling.

These compressed blocks are not only available for paving road beds, but possess utility as an artificial material for the construction of submarine or exposed sea walls, or for other building purposes. Experiments have shown that compressed blocks of this character can be used for the walls of fortifications with great advantage in comparison with natural stone.

T. S. Bale has proposed to lessen the danger of asphalt roadways to horses by rolling in it broken granite, or boulders, or very hard fired clay; to make roadways and tramways with blocks about 6 in. square, of clay and its compounds pressed and fired extremely hard, and used alternately with asphalt, cement, and wood, cork, or indiarubber.

For ornamental work, a foundation is made in the usual way with ashes and coarse asphalt, upon which a finer coating is laid an inch or more thick, which serves the purpose of a ground to throw up the other colours. Upon this is put a frame or mould of thin metal or wood for the pattern, and after being filled with enough of the required colour, it is lifted off, and the colour is found inlaid. Another plan is for more elaborate patterns, which are inlaid upon cement or asphalt slabs of convenient size, and then fixed in place on the walk or building. When cement is used the superfluous part is cleaned off at proper time to leave the colours clear.

Bale forms rink and other floors with plaster of Paris mixed with lime, alum, and white copperas to a paste, and made smooth and allowed to set.

T. Hyatt manufactures blocks and slabs from Portland cement, mixed with stone chippings, hardened by being allowed to remain for long periods soaking in water. Portland and other stones are imitated by the admixture of Keene cement with Portland cement. This mixture can be moulded by hydraulic pressure upon metal cores, for useful and ornamental purposes in building. Hyatt also combines fireclays with Portland cement in the construction of floors and roofs. White clay of Hanover, or other infusorial siliceous material is combined with Portland or other binding cement in moulded forms, and in making floors or roofs is fastened to the surface of solid wood by mushroom-headed nails.

A. C. Ponton applies sulphur to the production of an artificial stone from sand, loam, clay, gravel, with or without the addition of Portland cement.

The proportions are calculated by the amount of the interstices which the finer materials fill when mechanically mixed with the coarser. Moulds are filled with the materials, using compression, either by ramming, tamping, or rolling. The moulds are preferably porous, and are constructed of plaster of Paris, wood, papier maché, or cement. If it is wished to indurate rapidly, the filled moulds are packed inside an air-tight receiver, and the receiver and contents heated up to about 240° Fahr., thus removing the water contained in the material. The receiver is then submerged in molten sulphur.

When the materials have become saturated with sulphur the receiver is withdrawn, and the superfluous sulphur allowed to drain into the tank containing the molten sulphur. Where speed of induration is not required, the filled moulds are merely soaked in molten sulphur, and withdrawn from the tank containing the sulphur when sufficient saturation of sulphur is obtained.

In those cases where steam under pressure is available, it is preferable to steam jacket the tank for the supply of heat. A float and index is used to ascertain when the articles are saturated with sulphur, the float assuming a state of rest when the saturation is completed.

In those structural cases where it is necessary to resist the action of fire, Portland cement, or loam or clay, are used to bind the particles together.

The Strength of Cement and Concrete.—As the result of experiment as to the breaking weight of Portland cement weighing 112 lb. to the bushel, gauged neat, and also with different proportions of Thames, clean pit, and loamy sands, T. Grant, in a paper read before the Institute C.E., gives the following. When gauged neat the cement bore;—

	lb. a sq. in.		lb. a sq in.
1 week	445·0	6 months	978·7
1 month	679·9	9 ,, ...	995·9
3 months	877·9	12 ,, ...	1075·7

Thus in three months the cement bore about double the strain it did at the end of a week, and at the end of twelve months, 241·70 per cent. The following are the breaking weights of the same cement mixed with clean, sharp, Thames sand, in proportions varying from 1 to 1, to 1 to 5.

When mixed with an equal proportion of sand, the breaking weights are at;—

	lb.		Per cent. of the strength of neat Cement.
1 week	97·0	=	21·8
1 month	309·3	=	44·5
3 months	367·0	=	41·8
6 ,, ...	546·8	=	55·9
9 ,, ...	607·8	=	61·3
12 ,, ...	700·3	=	65·1

When mixed with twice the proportion of sand, the breaking weights are at;—

	lb.		Per cent. of the strength of neat Cement.
1 week	52·5	=	11·80
1 month	123·5	=	18·16
3 months	254·5	=	29·00
6 ,, ...	425·1	=	43·46
9 ,, ...	431·5	=	43·33
12 ,, ...	458·5	=	42·62

When mixed in the proportion of 1 of cement to 3 of sand, the breaking weights are at;—

	lb.		Per cent. of the strength of neat Cement.
1 week	27·0	=	6·07
1 month	58·0	=	8·53
3 months	135·5	=	15·43
6 ,, ...	232·4	=	23·74
12 ,, ...	320·6	=	29·90

When mixed in the proportion of 1 of cement to 4 of sand, the breaking weights are at;—

	lb.		lb.
1 month	32·5	6 months	157·0
3 months	109·0	12 ,, ...	221·6

When mixed in the proportion of 1 of cement to 5 of sand, the breaking weights are at;—

	lb.		lb.
1 month	21·0	6 months	95·5
3 months	88·5	12 ,, ...	122·3

With similar proportions of clean pit sand taken from the excavations, the strength is, in every case, much greater than in the cases described, where Thames sand was used. It will be perceived that the strength rapidly gains in proportion upon that of the neat cement. Thus, in the first case, that which was only 21·8 per cent. at the end of a week, and 45·5 per cent. at the end of a month, at the end of the year has increased to 65·1 per cent. of the strength of neat cement. With clean pit sand the corresponding tests of 1 to 1 show that the gain is much greater, increasing from 34·2 per cent. at the end of a week, to 74·0 per cent. at the end of a year. Again, if the breaking weights at twelve months, for the proportions of cement to sand of 1 to 2, 1 to 3, and 1 to 4, are multiplied by 2, 3, and 4 respectively, on the average it will be found that the normal strength of the neat cement (1075·7 lb.) is, as nearly as possible, diluted in proportion to the quantity of sand, the average numbers being 1066·1 lb., 1103·4 lb., and 1044·8 lb. This, however, does not hold good with the proportion of 5 of sand to 1 of cement, except where the sand is purest; the strength at the end of twelve months, multiplied as before by 5, being 611·5 for Thames sand, 1078 for clean pit sand, and 831 for loamy pit sand, against 1075·7, the normal strength of the neat cement.

The foregoing experiments, extending only to twelve months, still left some interesting points unsettled; as, for instance, the age at which cement, whether neat or mixed with sand, ceases to increase in strength; the age at which the several compounds of cement and sand approach nearest to the normal strength of neat cement, or, in other words, obtain their maximum strength; also, the most economical proportion of cement and sand, with an assumed minimum strength. The last point has been approximately ascertained, as it has been shown that with sand in the proportion of 2, 3, and 4 to 1 of cement, the sand simply acts as a diluting agent; but with sand in the proportion of 5 to 1 of cement, any imperfection in the sand materially affects the strength of the compound. It is only with clean pit sand that the full strength of the cement is obtained; the strength, 215·6, multiplied by 5, gives 1078 lb. against 1075·7 lb., the strength of the neat cement.

With the view of ascertaining, if possible, the age at which cement mixed neat and with sand attains its greatest strength, another series of experiments was commenced. The cement in this case weighed 123 lb. per imperial bushel. The breaking weights of the neat cement are at:—

	lb.		lb.
1 week	817·1	9 months	1219·5
1 month	935·8	12 „	1229·7
3 months	1055·9	2 years	1324·9
6 „	1176·6	3 „	1314·4

The same cement when mixed with an equal proportion of Thames sand broke at the following weights;—

	lb.		Per cent. of neat Cement.
1 week	353·2	=	40·78
1 month	452·5	=	48·35
3 months	547·5	=	51·85
6 „	640·3	=	54·42
9 „	692·4	=	56·77
12 „	716·6	=	58·27
2 years	790·3	=	59·65
3 „	784·7	=	59·70

The proportionate strength of cement and sand thus increases between three months and twelve months, at the rate of 2 per cent. every three months, but in the course of the second year only 1·38 per cent. per annum. In the third year there is no increase.

With cement gauged neat and kept for periods varying from seven days to twelve months, first, in water, secondly, out of water, in-doors, and thirdly, out of water, exposed to the action of the weather, at the end of twelve months the results are respectively as 1099, 827·4, and 719·6; that is, the cement which was kept out of water, in-doors, attained only 75·29 per cent. of the strength of that which was kept in water; while that which was out of water, and exposed out of doors, acquired only 65·48 per cent. There are considerable variations in the apparent strength at different ages, but the averages may be taken as 100, 80·64, and 76·8. Cement allowed to set under water seems, from these experiments, to gain strength from 24 per cent. to 30 per cent.

As to the relative strength of cement gauged with fresh water and with salt water, at various ages, from a week to five months, the difference, though not very material, is in favour of salt water. Therefore in the case of harbours, docks, and piers, where the water is either salt or brackish, there need be no hesitation in using salt water, either in making Portland cement concrete or in building. The best Roman cement is very inferior to Portland, especially when mixed with sand.

As to the strength of Keene's cement and Parian cement, in water and out of water, for periods varying from seven days to three months; at three months the strength of Keene's cement in water is 508·8 lb.; out of water, 720·5 lb.; or 41 per cent. more; Parian cement in water, 521 lb.; out of water, 853·7 lb.; or 64 per cent. more.

With Medina cement at various periods, from seven days to two years, the increase is from 211 lb. at seven days, to 476·9 lb. in twelve months, and 276 lb. in two years. There is a great falling off in the second year.

These three cements have only been used for internal architectural purposes.

The following table gives the number of tons required to crush bricks made of Portland cement neat, and with five different proportions of sand at three, six, and at nine months, at which different periods the strength of the neat cement bricks was 65 tons, 92 tons, and 102 tons respectively, or more than that of Staffordshire blue bricks. Bricks made of a mixture of sand with cement, in the proportions of 4 to 1 and 5 to 1, stand a pressure equal to the best stock bricks.

Compression of Portland Cement Bricks.

Size 9 × 4·25 × 2·75 = 105·18 cubic in.; area exposed to Pressure 9 × 4·25 = 38·25 sq. in.

Description of Bricks.	Average Pressure in Tons when Specimen first showed signs of giving.	Average Pressure in Tons when Specimen finally Crushed.
Neat Portland Cement	42·00	64·81
1 Portland Cement to 1 Pit Sand	29·24	42·53
„ 2 „	25·50	34·22
„ 3 „	19·99	24·52
„ 4 „	20·62	22·73
„ 5 „	10·29	16·37
(Made 3 Months.)		
Neat Portland Cement	58·35	92·01
1 Portland Cement to 1 Sand	32·82	59·39
„ 2 „	24·80	47·00
„ 3 „	19·42	36·81
„ 4 „	10·13	30·68
„ 5 „	11·91	26·29
(Made 6 Months.)		
Neat Portland Cement	37·00	102·19
1 Portland Cement to 1 Pit Sand	64·40	77·88
„ 2 „	51·13	62·28
„ 3 „	33·25	40·87
„ 4 „	25·38	37·71
„ 5 „	19·40	28·66
(Made 9 Months.)		

During six years the average strength of 1,369,210 bushels of Portland cement used in the Southern Main Drainage Works was 606·8 lb., being 52 per cent. above the standard first specified, and 21 per cent. above that subsequently adopted. The average weight a bushel was 114·15 lb., being 4·15 per cent. above the specified standard. Portland cement has been proved to be peculiarly suitable for hydraulic works, and may be procured in any quantity, and of the highest quality. Portland cement, if it be preserved from moisture, does not, like Roman cement, lose its strength by being kept in casks or sacks, but rather improves by age; a great advantage in the case of cement which has to be exported. The longer it is in setting, the more its strength increases. Neat cement is stronger than any admixture of it with sand. Cement mixed with an equal quantity of sand, may be said to be, at the end of the year, approximately three-fourths of the strength of neat cement. Mixed with 2 parts of sand it is half the strength of neat cement. With 3 parts of sand the strength is a third of neat cement. With 4 parts of sand the strength is a fourth of neat cement. With 5 parts of sand the strength is about a sixth of neat cement. The cleaner and sharper the sand, the greater the strength. Very strong Portland cement is heavy, of a blue-grey colour, and sets slowly. Quick-setting cement has generally too large a proportion of clay in its composition, is brownish in colour, and turns out weak, if not useless. The stiffer the cement mortar, that is, the less the amount of water used in working it up, the better. It is of the greatest importance that the bricks or stone with which Portland cement is used should be thoroughly soaked with water. If under water in a quiescent state, the cement will be stronger than out of water. Experiment has shown that cement kept in water was one-third stronger than that kept out. Blocks of brickwork or concrete made with Portland cement, if kept under water till required for use, would be much stronger than if kept dry. Salt water is as safe for mixing with Portland cement as fresh water. Bricks made with neat Portland cement are as strong at from six months to nine months as the best quality of Staffordshire blue bricks, or similar blocks of Bramley Fall stone or Yorkshire landings. Bricks made of 4 or 5 parts of sand to 1 part of Portland cement will bear a pressure equal to the best picked stocks. Portland cement concrete, made in the proportions of 1 of cement to 8 of ballast, in some cases, and of 1 to 6 in others, has been extensively used for the foundations of river walls, piers of reservoirs, and foundations generally, with the most perfect success; and it might be much more extensively used as a substitute for brickwork or masonry wherever skilled labour, stone, or bricks are scarce, and foundations are wanted at the least expenditure of time or money.

Wherever concrete is used under water, care must be taken that the water is still; as otherwise a current, whether natural or caused by pumping, will carry away the cement and leave only the clean ballast. Roman cement, though about two-thirds the cost of Portland, is only about one-third its strength, and is therefore double the cost, measured by strength. Roman cement is very ill adapted for mixing with sand.

Whilst Portland cement is the best that can be used by the engineer, it should not be used by anyone who is not prepared to take the trouble or incur the trifling expense of testing it; because if manufactured with improper proportions of its constituents, or improperly burnt, it may do more mischief than the poorest lime.

QUANTITIES used in making Brickwork Blocks, in Compo composed of Portland Cement and River Sand in equal proportions, each Block being 3 ft. cube = 1 cubic yard. February, 1865. Number of Bricks in each Block, 384.

Materials.	No. 1 Block. Gault Bricks with Frogs. Average, 8·75 × 4·1 × 2·75 = 98·6562.		No. 2 Block. Gault Bricks, Wire Cut, no Frogs. Average Size, 9·08 × 4·14 × 2·75 = 105·8.		No. 3 Block. Sand Stocks. Average Size, 9·08 × 4·21 × 2·76 = 105·7573.	
	bush.	cub. ft.	bush.	cub. ft.	bush.	cub. ft.
Cement weighing 112 lb. a bushel	3·615	4·6406	3·29	4·2187	3·29	4·2187
Sand	3·615	4·6406	3·29	4·2187	3·29	4·2187
Bricks	17·090	21·9236	17·98	23·0786	18·29	23·4780
Totals	24·320	31·2048	24·56	31·5160	24·87	31·9154

The following table shows two series of experiments as to the quantities of Portland cement, sand, and water used in making one cubic yard of compo, or cement mortar.

P.C. Sand.	FIRST SERIES.	Bushels.	SECOND SERIES.	Bushels.
1 to 1	Cement	12¼	Cement	13
	Sand	12¼	Sand	13
		24½		26
	56 Gallons of Water.		48 Gallons of Water.	
1 to 2	Cement	8¼	Cement	8½
	Sand	16½	Sand	17
		24¾		25½
	44 Gallons of Water.		36 Gallons of Water.	
1 to 3	Cement	6½	Cement	6¼
	Sand	19½	Sand	18¾
		26		25
	46 Gallons of Water.		28½ Gallons of Water.	
1 to 4	Cement	5¼	Cement	5
	Sand	21	Sand	20
		26¼		25
	47 Gallons of Water.		38 Gallons of Water.	
1 to 5	Cement	4¼	Cement	4⅛
	Sand	21¼	Sand	20⅝
		25½		24¾
	51 Gallons of Water.		34 Gallons of Water.	

As a rule the strength of Portland cement increases with its specific gravity.

In the discussion on this paper, R. Rawlinson remarked that there was one application of Portland cement not generally known, its use, when of good quality, under water, by the aid of a diver. He had used it to make a joint between iron and iron, under a 90-ft. head of water, with perfect success, to keep out a quicksand. He had occasion to sink a well where there was a quicksand at the depth of 90 ft., overlaid by a thick bed of marl, and underlaid by new red sandstone rock. The ordinary iron cement, of iron borings and sal-ammoniac, would not set, but washed out. He sent down pure, stiffly-made Portland cement in buckets; this was put in place by divers, and set perfectly, and remained for three or four years, though exposed to a severe strain by the constant pumping. All the mortar used at the Liverpool Docks was made with sea sand, and mixed with salt water.

G. F. White stated that the engineers of the Ponts et Chaussées, in 1850, had proposed and applied numerous tests, which had not been materially varied to the present day, and which, for the sake of comparison with the Board of Works tests, might be given as follows;—

Specific weight, 1200 kilogrammes a mètre cube, or 103 lb. an imperial bushel.

Tensile strain, tried on bricks with the same sectional area as employed by the Board of Works, viz. 2·25 square inches;

Neat cement	2 days	64 kilogrammes, or	140 lb. a brick.
”	5 ”	128 ”	280 ”
”	30 ”	240 ”	530 ”
Cement 1 part	5 ”	64 ”	140 ”
Sand 2 parts	30 ”	128 ”	280 ”

The Board of Works tests were of a threefold character. The cement must be of a given specific weight. When gauged neat, it must have a certain resistance to tensile strain. It must bear immersion in water, without sign of cracking. The tensile strain, at first fixed at 400 lb., had been raised to 500 lb., and the specific weight, fixed originally at 110 lb., had been raised to 112 lb. a bushel. It was to this test of 112 lb. a bushel, which indicated a very heavily burnt cement, that White desired to direct some attention, as pressing severely on the manufacturers, without, as he believed, conferring any corresponding benefit on the engineer. The way in which it affected the manufacturers was as follows;—The less the concentration given to the cement by burning, the greater was the volume of cement that could be obtained from a given quantity of raw material. If a certain quantity of chalk and clay, calcined to the specific gravity of 104 lb. a bushel, produced 21½ bushels of cement to the ton, the same quantity of raw material, burnt to weigh 112 lb. a bushel, would produce only 20 bushels to the ton, and occasion the manufacturer a loss in volume of 7½ per cent. Cement of so high a specific gravity as 112 lb., involved a much larger consumption of the fuel employed in burning it, an item which, under the most favourable circumstances, counted for nearly one-third of the prime cost of the cement. The destruction of kilns, and of the machinery employed in grinding the cement, was enormously increased by the intensity of the heat required to produce it, and by the hardness of the material to be ground. The quantity of this highly calcined and heavy cement, that could be produced in any one kiln, bore only a certain proportion to a residue, which was not sufficiently burnt to produce cement weighing 112 lb., but which could be employed advantageously in the manufacture of cement that was intended to set more quickly, and to weigh only 104 lb. a bushel. Looking at the question as it affected engineers, this heavily burnt cement was a dangerous cement to use. It was well known to manufacturers that to be able to push the calcination far enough to produce a cement of a uniform gravity of 112 lb., it was needful to combine more lime with the clay than was required for lighter burnt cement; and that, in so doing, there was the risk that a perfect amalgamation of the lime and clay would not be effected; but some of the lime, being left in a free state, would be liable to be slaked by water, or even by the moisture of the atmosphere, and produce, sooner or later, disintegration. The next consideration was the slowness of the setting of this heavily burnt cement. It would not set in running water. Portland cement of English manufacture had been successfully employed for concrete *en masse*, in constructing underwater foundations. It was quite intelligible that, though the cement of 112 lb. would set too slowly for this purpose, a lighter burnt cement would effect the desired object. To lose sight of this, and to insist that all cement, whatever its destined use, should be thus concentrated in burning, would be simply to deprive it of one of its most valuable properties—that of setting rapidly under water. Another inconvenience to which this heavily burnt cement exposed the engineer, was the almost certainty that it would not be properly ground. Theoretically, the cement should be an impalpable powder, and every grain of sand a matrix, round which the cement should form a film, or coating; but this could scarcely be the case with a material which it was so difficult to reduce to powder. On the contrary, if carefully scrutinized by passing it through a sieve or by washing it, a considerable residue of particles resembling sand would be found, comparatively inert in their character, with very feeble setting properties, and of a nature to diminish the amount of real sand which the cement would otherwise carry. Another objection was the loss of volume which would be sustained by the engineer, equally with the manufacturer, if he were to become the buyer of cement by the ton, instead of having it furnished through the contractor. French engineers regulated this question by procuring a cement of sufficient density to pass their tests, while stipulating that it should not exceed that weight, so as to produce a needless loss in volume. The test of specific weight was too variable to be relied on, if unaccompanied with other conditions.

In a second paper on this subject, J. Grant gives the strength of neat Portland cement as mixed by hand, and as ground in a mortar mill for 30 minutes. At the end of a month that which was ground in a mill had less than three-fourths the strength of that which was mixed by hand. The maximum strength of that mixed by hand seems to have been attained at five months, and that ground in a mortar mill at one month, the greatest strength of the former being nearly double that of the latter. The strength of that which was mixed by hand was maintained, while that which was ground in a mortar mill declined, from the maximum in each case to the end of the experiments. This result was probably due partly to crystallization, or the setting, having been interrupted by continued agitation, and partly to the destruction by attrition of the angular form of the particles.

As to the tensile strain required to separate bricks cemented together with Portland cement and lime mortars, experiments would require to be greatly extended before any very trustworthy deductions could be made. Pressed gault bricks show the lowest amount of adhesiveness, partly because of their smooth surface, and partly because in making them some oily matter is used for lubricating the dies of the press through which they are passed before being burnt. In the case of perforated gault bricks the cement mortar seems to act as dowels, and the results are consequently high. Suffolk and the Fareham red bricks, which each absorb about a pound of water per brick, adhere much better than Staffordshire, which are not absorbent. This shows the importance of thoroughly soaking bricks which are to be put together with cement, as dry bricks deprive the cement mortar of the moisture which is necessary for its setting.

The strength of Portland cement bricks tested by crushing, appears to increase the denser the brick. When the cement is in proportion to the sand less than 1 to 2, or 1 to 3, those dried in air bear a greater pressure than those kept for twelve months in water. This would lead to the inference, that when the quantity of cement is small, bricks or blocks of concrete should be kept some time out of water, and be allowed to harden before being used.

Contrasting the strength of these concrete bricks with the different clay bricks, it will be seen that, down to the proportion of 5 to 1, the former compare favourably. Bricks made of neat cement bore a pressure equal to that of Staffordshire blue bricks or of best Fareham red bricks. Cement bricks made in proportions of from 2 to 1 of cement, to 5 to 1, are equal to picked clay bricks. If concrete bricks were more compressed their strength would be greatly increased. Concrete blocks made with the largest proportion of cement to ballast are the strongest, the strength being nearly in proportion to the quantity of cement; it is desirable to spend no more time than is absolutely necessary to effect a thorough admixture of the cement with the sand and gravel. Compressed blocks are apparently stronger than the uncompressed blocks in a larger proportion than their difference in density.

Concrete made of broken stone or broken pottery is much stronger than that made of gravel. This is no doubt due partly to the greater proportion of cement absorbed in the latter case in cementing the finer particles of sand, and partly to the want of angularity in the gravel. Compression, and an increase in the proportion of cement, alike increase strength. In making concrete bricks or blocks of moderate size compression might be applied with advantage; but with large masses of concrete it would be difficult to do so, without running the risk of interrupting the process of crystallization or setting, which commences immediately on the application of moisture. The cost of labour so applied would therefore be better employed in a larger admixture of cement. For the same reason that absorbent bricks should be thoroughly soaked with water before being used, the broken stones, bricks, or other materials used in making concrete should be saturated with water before the cement is applied.

Lieut.-Colonel Scott remarked in the discussion on the second paper, that Grant had brought up the strength of Portland cement to a high standard. Those in the habit of using large quantities of Portland cement were aware that at times it expanded to an extraordinary degree. This was due generally to too large a quantity of chalk having been used in its preparation. With a large proportion of clay there was greater safety, though somewhat less strength. As to cement mortar when beaten up afresh, though first losing strength, afterwards becoming stronger again, it might be explained by assuming that the cement might have contained some particles which had an expansive tendency. In using lias lime, unless it was ground to a fine powder, and the slaking allowed to go on some time before use, the work was apt to get distorted, because those particles which were uncombined with water expanded in the work when hydration took place, and burst it. There was continued expansion of some of the lime particles through slaking, till the material was brought wholly into the state of hydrated silicate of lime, when it again gained in strength by the quiet and gradual rearrangement of the particles, such as occurred with hydraulic limes, without any disturbing element. There was a new mode of using lime, which had been adopted in the buildings at South Kensington. If in the ordinary slaking of lime just sufficient water was added to bring it to a dry impalpable powder, this powder would have a bulk sometimes much greater than that of the original lime, and if made into paste would, when it dried, exhibit a considerable degree of porosity. It could be imagined that if the lime, instead of being slaked, were ground to powder and induced to set as cement, with its original density, much greater strength would be attained in the solidified mortar. In the use of lime the combination with water took place first, and then subsequently the solidifying action went on. If it was hydraulic lime, a silicating process was set up after slaking, and a fresh arrangement of particles took place. In the case of cements the slaking and the setting went on simultaneously, and the water entered at once into combination with the cement to form a stone-like substance. If by any means lime could be induced to combine with the water slowly, so as not to burst with the heat, a much better result would follow than from the ordinary way of using it. This, in fact, was what had been accomplished by the present mode of making mortar, and the general method of procedure was as follows, the lime used at Kensington being ordinary grey lime finely ground. First 5 per cent. of plaster of Paris, as compared with the quantity of lime to be used, was mixed in a bucket of water, making a milk of sulphate of lime. This was thrown into the pan of a mortar mill, and the ground lime added gradually; instead of the lime slaking as it would when treated with water only, it showed no symptoms of slaking, and was brought to a thin paste without any sensible increase of temperature. When that was done, sand was added, and for most purposes as much as 6 parts of sand to 1 of lime. In thin brickwork greater strength was obtained with grey lime treated in this way, with 6 parts of sand, than with Portland cement with 4 parts of sand. The same results would not follow the use of grey lime in very damp situations or under water; in such situations another set of phenomena came into play. The process described would not give setting property under water if the lime did not possess it before. It might be thought that the watter-setting property was destroyed by the plaster of Paris, which was itself soluble, but that was not the case. The quantity of plaster of Paris did not exceed 0·75 per cent. of the mortar; and in three or four weeks crystallized out in the pinhole cavities in it, where it showed itself in crystalline plates. In proportion as the percentage of clay in the lime employed increased, so was the mortar more suitable to be used under water.

With a view of adding to the existing knowledge on this subject, C. Colson has recorded the details of the tests made by him during the execution of the works of the Portsmouth Dockyard Extension, the results being communicated to the Institute of Civil Engineers. The specification provided that the cement should be of the best quality, ground extremely fine, and should weigh not less than 112 lb. to the imperial striked bushel, as poured from a sack into the measure. The cement was to bear a tensile strain of 450 lb. on 2¼ sq. in. without breaking, at the end of seven days' immersion in water. It was also provided that samples for testing should be taken from every tenth bag, if required. It was not, however, deemed necessary to proceed to the extreme limits stipulated for in the specification; but, on the arrival of each cargo, sufficient cement was taken to make seven briquettes, four of which were placed in water as soon as they were sufficiently set to admit of their being removed from the moulds, the remainder being kept dry. At the expiration of seven days three of the wet briquettes and the three dry ones were tested in the machine, the remaining wet one being reserved. With regard to the method for weighing the cement, it was found, after repeated trials, that a uniform result could not be attained by simply pouring the cement out of the bag, as it was impossible to maintain a uniform rate of delivery. If the cement was allowed to fall from the bag too quickly, the measure became filled with a mass of cement of the same density as when in the bag, in which it had become consolidated by being shaken and moved about. To obviate this difficulty, and to equalize the density in the measure as much as possible, an ordinary hopper stool was adopted. This was about 2 ft. 6 in. high, with a shoot fixed on the top; the lower end or neck was contracted to 7 in. by 2 in., to prevent the cement from falling into the measure in heavy masses, in case it should escape from the bag too quickly. The measure, heaped up, was allowed to stand for a few minutes, in order that the cement might settle. When no further subsidence was observed the surplus was struck off the top, and the rest weighed. By this method a uniform density was obtained.

The average weight per bushel after screening off the coarse cement was 106 lb., against 115 lb. before screening, as delivered on the works. These results show that the cement, as received from the manufacturer, is affected to the extent of between $\frac{1}{4}$ and $\frac{1}{5}$ of the gross weight, or about 21½ per cent, by coarse grinding.

Undoubtedly the fairest way would be to test cement at thirty days, inasmuch as the harder burnt varieties, requiring a longer time to set, are placed at a considerable disadvantage compared with the quicker setting cements when tested at the end of seven days. They do not show such good results as would be the case if a longer time were allowed.

Not only does the demand for high tensile strength at seven days practically exclude from competition all the harder burnt, slower setting, though ultimately stronger cements, but it has the effect of forcing the quicker setting cements to such a degree, that the risk of the presence of free lime, and consequently the danger of expansion, is augmented. Much can be said on the other hand in support of immediate strength, which in some cases is necessary.

For mortar or concrete destined for building construction, it is undoubtedly injurious to employ other than fresh water, on account of the deliquescence of the salts contained in the sea-water, particularly during humid weather; but in coast or harbour works there appears to be no valid objection to its use.

The conditions of manufacture affecting the tensile strength and rate of setting of Portland cement may be divided under four heads. The proportions of chalk and clay; the degree of calcination; the degree of fineness; the age of the cement.

It is impossible to establish any fixed proportion for the chalk and clay, as it must depend entirely upon the quality of each considered separately. Grey chalk, containing a large percentage of clay, would require less of the latter to be added; whilst white, or upper chalk, being almost pure lime, would require more clay. The clay, if obtained from the beds of rivers flowing through a chalk district, may contain lime, which would necessitate a reduction in the quantity of chalk to be added in the manufacture of the cement. The constituents of these ingredients can only be ascertained by analysis, careful tests, and observations; the knowledge thus obtained forming the basis of the proportions of chalk and clay to be adopted in the manufacture of Portland cement in each particular locality. It may be stated in general terms, that where a high tensile strength is demanded, a greater proportion of chalk must be employed. This, if properly burnt, will produce a slow-setting, but eventually a very strong cement. There are, however, reasons why, in general practice, a high proportion of chalk should be avoided; the principal one being the great danger of an excess of that ingredient to produce free lime, which would cause the cement to swell and crack, and eventually fall to pieces. Cement with a high proportion of chalk has not the same hydraulic properties as cement with a less percentage of chalk, a full proportion of clay being necessary to ensure these. On the other hand, an excess of clay will give a quick-setting, but, at the same time, a very weak cement, with a muddy appearance and yellow colour.

As regards the proportions affecting the rate of setting, it appears that a high proportion of chalk, not in excess, will cause this action in the cement to be slow, whilst an excess of chalk, producing free lime, will evolve considerable heat on being gauged, causing the cement, apparently, to set much more quickly; but when in this condition there is the greatest danger of its flying. The addition of clay increases the rate of setting, and especially when present in excess. Afterwards it will harden very gradually, and that only to a limited degree.

With reference to the degree of calcination, the quality of the cement depends, to a great extent, upon the perfection to which the operation of burning is carried. Care is required in putting into the kiln the proper proportions of cement and coke. Cement, when properly burnt, should have the appearance of a hard clinker just on the verge of vitrifaction; in proportion to the high degree of burning, short of excess, so is the strength of the cement improved.

With regard to the increased tensile strength of the fine as compared with the coarse cement when mixed with sand, it may be accounted for by the latter containing a large proportion of unground particles which, although acting as a bond when gauged neat, would, on the addition of sand, be distributed through the mass, thereby reducing the influence they would have as a key; the actually effective cement being the difference between the original quantity and the proportion of coarse or unground it contains. This proportion is ordinarily about 21 per cent. The cement would, therefore, be reduced in about this proportion, whilst the sand would be augmented; thus, in the case of 1 to 1, the actual proportions would be ·79 of cement to 1·21 of sand. In the case of the fine cement, the proportions would be as stated, the mass therefore containing a greater quantity of effective cement, which would go far to account for the superior tensile strength ascertained from these experiments.

The quantity of water used in gauging the cement has great influence upon the tensile strength. If an undue amount be employed, it is reduced to a considerable extent; on the other hand, if the quantity be as small as possible consistent with proper manipulation, the result will be much higher. From numerous experiments and observations it was found that, as a general rule, a proportion of 1 of water to 3 of cement by measure, or 1 to 3½ by weight, was the best, both as regards convenience of mixing and results. With a much less quantity, the gauging would be so stiff as to render the manipulation most difficult, the risk of air-holes, the reduction of which to a minimum is a point to be particularly attended to, would be augmented; the angles of the mould would be imperfectly filled, and generally a very imperfect briquette formed; consequently the results of such tests would be unsatisfactory and unreliable. A much greater quantity of water would have the effect of reducing the tensile strength, rendering the results of tests equally unsatisfactory and unreliable. Of course, in general practice, it will be found that a slight variation in the above-mentioned proportions will be necessary, depending upon the age and degree of fineness of the cement, but only to a limited extent.

The age of Portland cement, although strictly not a condition of manufacture, is an important element in its economical and safe use. Cement not only improves generally by keeping, but the older the cement the less danger will there be of its flying, inasmuch as free lime, arising from an excess of chalk, would be acted upon by the atmosphere, causing it to slake, and reducing the danger of expansion to a minimum. The age has also been found to exert considerable influence upon the rate of setting, causing it to require a much longer time to set than new cement.

The following analyses of constituents and cement made therefrom, will show the chemical changes occurring in the manufacture;—

Analyses of raw materials used by the Burham Cement Company—

Gault clay—		Grey Chalk—	
Silica	46·61	Carbonate of lime	87·50
Alumina	16·06	Silica	7·00
Oxide of iron	6·07	Alumina	1·15
Carbonate of lime	25·06	Magnesia	1·00
Magnesia	·60	Oxide of iron	·30
Potash	·60	Organic matter and water	3·05
Water and organic matter	5·00		

Analysis of Portland cement manufactured by the Burham Cement Company—

Alumina	12·25	Soda	·75
Oxide of iron	4·30	Silicic acid	25·00
Magnesia	·30	Clay sand	3·00
Pure lime	50·00	Moisture	1·00
Sulphate of lime	2·00	Loss	·55
Potash	·85		

Analyses of raw materials used by Hooper and Co.—

Wet Clay—		Raw Chalk—	
Carbonate of lime	2·79	Carbonate of lime	76·00
Silica	24·86	Silica	1·09
Alumina	5·12	Alumina	·73
Oxide of iron	1·08	Oxide of iron	·36
Potash and soda	1·39	Carbonate of magnesia	·06
Water	64·76	Water	21·49
		Loss	·27

Analysis of Portland cement manufactured by Hooper and Co.—

Lime	64·36	Oxide of iron	1·58
Silica	26·42	Potash and soda	1·37
Alumina	6·22	Magnesia	·05

Good Portland cement, in its dry, ungauged condition, is of a uniform dull grey colour; occasionally a slight greenish hue is observable, sometimes replaced by a slight buff tint. A yellow or earthy colour is almost invariably indicative of inferior quality. The colour can be best observed by pressing a small quantity on a sheet of white paper with a clean, smooth trowel, or a piece of sheet glass.

I. J. Mann suggests that the operation of weighing should be discarded, and the specific gravity be taken instead. That this has not hitherto been done is probably due to the trouble and difficulty experienced in obtaining the specific gravity by the ordinary method. In the case of Portland cement a liquid must be used which does not chemically affect it. The specific gravity of this liquid has also to be taken and the results reduced to the standard of distilled water, involving tedious arithmetical calculations. To obviate these difficulties, a simple gravimeter has been devised. It consists of a small glass vessel holding, when filled to a mark on the neck, a given quantity of liquid, and of a glass pipette furnished with a graduated stem and stopcock, and containing, when filled to a mark on its upper extremity, a volume of liquid equal to that held by the first-mentioned vessel, minus the quantity displaced by 1000 grains of the densest substance intended to be examined.

In using the gravimeter the pipette is filled to the mark with paraffin, turpentine, spirits of wine, or any other liquid which does not act on the cement, preferably paraffin; 1000 grains of the cement are then introduced into the smaller vessel, which is placed under the pipette and filled to its mark. Before this is quite completed the vessel may be corked, and the contents shaken to remove small air-bubbles entangled in the cement. The height of the column of liquid remaining in the pipette determines the specific gravity, which can be at once read off on the graduated stem. The denser the substance operated upon, the less liquid will be displaced in the smaller vessel, and therefore the less will remain in the pipette, and *vice versâ*.

C. Colson has also experimented on the comparative tensile strength of grey lime and Portland cement mortar, to ascertain what proportions of Portland cement and sand would produce a mortar equal in strength and as convenient to work as grey lime mortar, the proportions ordinarily adopted for constructive purposes. The mortar was mixed to a working consistency, equal, in fact, to the condition in which it would be used in the work. The mass was then moulded in the frames used for testing Portland cement, where it remained until sufficiently hard to admit of removal. At the expiration of six months the blocks were tested for tensile strength. With regard to the lime mortar, containing 2 sand, 1 lime, 1·33 water, the fractured blocks showed that induration, or the chemical action of setting, had penetrated only to the extent of from $\frac{1}{8}$ inch to $\frac{3}{16}$ inch, but in the majority of instances to only $\frac{1}{8}$ inch. The remainder of the area, although dry, and moderately hard, had become so mainly from the evaporation of the moisture originally contained in the mass, and in no sense from the absorption of carbonic acid. It was possible, moreover, to crush it on the hand without any great exertion of force. The cement mortar, mixed in the proportions of 6 sand, 1 cement, 1·26 water, was of such a raw, harsh, character that it would be practically impossible to use it in a satisfactory manner. To render it somewhat more convenient for working, a small quantity of lime or yellow loam was added, rendering the mortar more plastic and tenacious. This addition of lime and loam reduces the initial strength of cement mortar considerably, the reduction due to the addition of loam being more marked than by the addition of lime. The quantity of unslaked lime or loam, $\frac{1}{12}$ the bulk of sand, was found to be as small a proportion as could be used, to give the necessary tenacity.

As regards the comparative adhesive power, it may be stated that the adhesive power of mortar, mixed in the proportions of 8 of sand to 1 of cement, with the addition of loam, was superior to grey lime mortar mixed in the proportions of 2 of sand to 1 of lime.

C. Colson has made numerous experiments on the strength of Portland cement concrete arches and beams to ascertain the relative supporting power of masses of concrete equal in quality and practically so in bulk, but differently disposed. It was also desired to show the relative supporting power of arches of the same span, rise, and thickness at the crown, composed of porous and non-porous material respectively, such as shingle and broken bricks, but mixed in the same proportions. The proportions, in the experiments in which shingle was used, were 6 of screened harbour shingle, 3 of sand, and 1 of Portland cement. The proportion of sand was determined by the measurement of the quantity of water required to fill the interstices of the shingle when placed in a known cubic measure. In mixing the concrete as little water as possible was used consistent with thorough manipulation; and in depositing upon the centre great care was taken that there should be no horizontal beds or laminations, but that the whole should form a thoroughly homogeneous mass.

No. 1 experiment consisted simply of a beam of concrete, mixed in the proportions as explained, 9 ft. long, 1 ft. 9 in. wide, and 9 in. deep; the distance between the supports was 8 ft. 3 in., with a bearing of 4½ in. at each end. Fourteen days after mixing the supports were removed, when the beam suddenly gave way near the centre. The fracture showed that the concrete was perfectly sound, there being no vacuities whatever to cause a diminution of effective sectional area.

No. 2 experiment consisted of a concrete beam similar in all respects to No. 1, being made from the same mass and deposited at the same time. In consequence, however, of No. 1 having failed on the removal of the supports at fourteen days, the supports were not removed in this case till twenty-one days after mixing. At this interval the beam stood perfectly sound, and remained unsupported for a further period of seven days, when it was tested, and broke under a central load of 5 cwt.

No. 3 experiment consisted of a portion of No. 1 beam, 4 ft. 6 in. long, placed on supports 3 ft. 9 in. apart. This beam supported a load of 7·50 cwt. for seven days, when the load was increased to 13·75 cwt., under which load the beam failed twenty-eight days after mixing.

No. 4 consisted of a portion of No. 2 beam, 3 ft. 9 in. clear of the supports, and tested immediately after No. 2, at twenty-eight days after mixing. This beam failed under a load of 1·044 ton placed at the centre.

In each of these experiments the beams broke suddenly, without the least evidence, either by gradual cracking or otherwise, that the limit of load had been reached. One point, with regard to Nos. 3 and 4, deserving notice, is the difference in the load borne by each before fracture took place, the interval of time being the same. It is possible that in the case of No. 3, which consisted of a part of No. 1 beam, the portion appropriated may have been slightly strained at the time of the first fracture on the removal of the supports at the expiration of fourteen days.

The foregoing experiments being upon beams resting simply on vertical supports, it was desired to know what increase of resistance to fracture would be derived from the ends of the beam being blocked in such a manner as to secure perfect rigidity. Sufficient concrete was therefore mixed in the proportions before described to form two beams. One, No. 5, was formed with the ends resting on piers, as in the case of the previous experiments. The second, No. 6, was formed between two counterforts of the wall, in which bearings 4½ in. deep had been cut. After an interval of fourteen days the supports were removed, when No. 5 beam broke with its own weight in exactly the same way as No. 1. Having in view the first failure, additional precautions were taken in removing the supports, the folding wedges and bearers being all planed true in order to reduce the friction to a minimum. The circumstances attending the failure of these two beams being precisely the same, lead to the conclusion that the strength of the concrete as used, at fourteen days' interval, was not sufficient to withstand the tensile strain at the centre due to its own weight. The supports were removed from No. 6 beam at the same time, no sign whatever of weakness being observed. After remaining unsupported for a further period of sixteen days, the beam was tested by placing weights on the centre. Under 0·25 ton a faint crack was observed at the centre through the whole width of the beam; with 0·635 ton it had increased as nearly as could be determined to half the depth, 4½ in., and opened to about $\frac{1}{16}$ in. at the lower surface. The full extent of the fracture probably exceeded this, although not apparent on the surface. The load at the centre was ultimately increased to 1·292 ton, when the beam broke. This experiment shows the necessity of guarding against the possibility of lateral movement, in the slightest degree, in the supporting girders of a floor.

Experiments Nos. 7 and 8 were made to compare the gain in strength derived from a different disposition of the same bulk of concrete. The same proportions and dimensions were preserved, but the mass was deposited in the form of an arch with a rise of 9 in. at the centre. The supports were removed from both arches at the expiration of sixteen days; there was, however, no necessity for their remaining supported for so long a time, as shown by subsequent experiments on arches of nearly double the span.

No. 7. Testing was commenced when the concrete was twenty-three days old. When loaded with 1·75 ton, a pig of iron, weighing 2·85 cwt., fell on one of the haunches, carrying away a portion. The arch then stood for two days with a load of 3 tons on the centre. Under a load of 4·50 tons slight evidence of distress was observed at the crown, and with a load of 5·50 tons the arch failed by the complete crushing of the material at the centre.

No. 8. The testing of this arch commenced at twenty-eight days after mixing the concrete. When loaded with 5 tons, the testing was suspended for three days; it was then resumed, and with a load of 6·75 tons the arch failed. The slight indications of distress observed in the previous experiment appeared in this case, only immediately before the fracture of the arch.

No. 9. In this experiment the arch was 13 ft. 9 in. between the abutments, 1 ft. 9 in. wide, and 9 in. thick at the crown, with a rise of 9 in. Exactly the same proportions of shingle, sand, and cement were used. The centring was removed at seven days from the date of mixing the concrete, and the arch was tested at twenty-one days. A gauge was fixed in order to ascertain the amount of deflection due to the imposed load, which consisted of pig-iron ballast applied at the centre of the arch. With a load of 4 tons slight signs of distress were observed at the crown, when the gauge registered a deflection of $\frac{1}{8}$ in. With an additional load of $\frac{1}{2}$ ton, = 4·50 tons, the arch suddenly failed, with no greater indication of distress than was previously observed. The greatest deflection registered was $\frac{3}{16}$ in.

No. 10 consisted of an arch of the same span and dimensions, constructed and the centring removed on the same dates as No. 9, but tested after one month. With 3·14 tons at the centre this arch failed, without even the slight warning observed in the previous experiments.

The concrete for the last two experiments was mixed in one mass as regards proportions of cement, sand, and shingle. No. 10 was, however, made much wetter than No. 9, to ascertain the effect of an excess of water upon the concrete. Judging from the results of these experiments the effect was to materially reduce the strength of the concrete. This was also found to be the case when concrete blocks were subjected to compression in the hydraulic press. These blocks, 6 in. × 6 in. × 6 in., were composed of the same proportions of cement, sand, and shingle, as used in the arches. An equal number was mixed with a maximum and minimum of water and tested when six months old. The same effect was also observed when broken bricks and broken Portland stone were used for the cement.

The concrete for Nos. 11 and 12 experiments was composed of broken bricks, mixed in the same proportions as used for the shingle arches, viz. 2 to 1 of broken brick and sand, and 3 to 1 of sand and cement; before mixing, the broken material was well damped. The necessary bulk of concrete for both arches was mixed in one mass and deposited in position at the same time. The centrings were removed in both cases seven days after mixing, and the arches tested at twenty-eight days. In No. 11 experiment slight evidence of distress at the crown became apparent under a load of 6 tons on the centre, and with 6·77 tons the arch failed.

No. 12 was tested on the same day as No. 11 arch, and supported a load of 6·50 tons before any indication of distress was observed; the load was then gradually increased to 7·064 tons, under which the arch failed.

The superior strength of the arches in the last two experiments is evidently due to the more absorbent and angular character of the material. The appearance of the fractures in the two cases of shingle and broken brick, showed a marked difference. In the first case, the strain destroyed the adhesive power existing between the shingle and the matrix; in no instance was a stone observed to be fractured, the casts being, as a rule, clearly defined in the cement. In the second case, the superior adhesive power existing between the broken brick and cement matrix was manifest; in but few instances had the cement left the surface of the brick, the general characteristic being that of complete disintegration of both brick and matrix.

CHIMNEY SHAFTS.

Chimney shafts are constructed for a twofold purpose. To cause a sufficient flow of air, or draught, through the furnace, to maintain the perfect combustion of the fuel with the least waste of heat; and to discharge at a great height the heated air and smoke, which, by reason of the noxious products contained, would be very injurious if ejected at a low altitude.

When used in conjunction with a steam engine, the success of the firing, in getting up steam quickly, and keeping it up steadily, depends in a great measure on the proper construction of the chimney; for without a properly regulated draught it is impossible to obtain a perfect combustion. Factory engineers, however, differ widely as to the best form and construction of a chimney for attaining the principal end in view, namely, the best draught at the least expense; the problem being one of those which present a wide field for inquiry, and admit of many different methods of solution, according to the end in view. For it will be evident that the velocity of the draught should be regulated by the work which the chimney is intended to perform; a steam engine shaft requiring a much sharper draught than one in connection with brick or lime kilns, and a forge chimney a sharper draught still. It will generally be found that with a draught in the chimney of less than 0·5 on the pressure gauge, the firing of the furnaces will be a constant toil to the fireman, he will be unable to avoid making a large quantity of black smoke, and in case of an extra demand for steam he will be unable to meet it; for no coaxing of a fire will make it burn brightly, or produce the red glow which is the perfect condition for raising steam, without a full command of draught. According to the Lancashire practice, a steam engine chimney, leaving all considerations of cost out of the question, cannot be too large nor too powerful, provided it is supplied with efficient means for checking the draught, by properly fitted dampers or otherwise, whereby the supply of steam can be readily controlled at any moment, so as to work the engine at one-half its full power, and using considerably less than one-half the power of draught of the chimney. For this purpose the ordinary damper, say 3 ft. long, of a 30-horse-power engine ought to be open only to the extent of 3 to 6 in., thus having a surplus draught always at command for emergencies. In every case the proper regulation of the damper will be found to be of extreme importance; a very nice adjustment being necessary to produce the best effect, either too much or too little air causing a great loss of fuel, and consequently a corresponding loss of power. An intelligent fireman, however, soon finds out by experience the proper height or opening of damper for doing the required work with the least consumption of fuel. The best chimney draught, for a steam engine, takes place when the absolute temperature of the gas in the chimney is to that of the external air as 25 to 12; another practical rule is, that in order to ensure the best possible draught through a given chimney, the temperature of the hot gases, in the chimney, should be nearly but not quite sufficient to melt lead; that is, about 600°. With steam boilers the heat of the air should not exceed 600°, and ordinary, well-burnt stock bricks will be found to stand this temperature well; but with reverberatory and other brick furnaces, the air is often of a temperature of 2250°. For such cases the chimney should be lined with firebrick throughout; and as the cohesion of mortar is soon destroyed with such high temperatures, there should be wrought-iron bands round the outside of the shaft, at regular intervals from top to bottom.

However well shafts may be erected, they are liable to be injured by lightning or by high winds. As regards the former, the chimney should be protected by lightning conductors. As regards the latter, the force of the wind in England rarely exceeds 50 lb. a sq. ft., even in great storms, although it has been known occasionally to rise to 70 or 80 lb. a sq. ft. It has, however, been calculated that with an ordinary well-built chimney the force necessary to overturn it would be 110 lb. a sq. ft. In the case of a severe gale of wind, if the chimney has a steady rocking motion, like the swing of a pendulum, it is probably safe; but if it has a swaying motion like a tree bent by a blast, and recovering itself during the lull, its eventual fall is almost certain.

The questions of most interest in connection with large chimney shafts, either in erecting a new shaft or rebuilding an old one, are the external and the internal proportions.

As regards the external form, of which Figs. 824, 828, and 832 are examples, there is no reason why a chimney shaft should not be both an ornament to the surrounding objects, as well as practically the best that could be constructed for the purpose required. Even in the case of a circular shaft of perfectly plain and regular outline, careful selection and contrasting of bricks of various colours, in bands or other simple, regular patterns, or a variation in the colour of the mortar, will often add considerably to the architectural appearance. The cap frequently receives the most decoration, but in very high shafts this is the last thing which should be decorated, as there is no use in elaborately carving the top of a chimney shaft 200 or 300 ft. high; neither is a heavy stone cap, several tons in weight, required for the stability of the shaft. A slight corbelling out of the brickwork for a few courses in height, or a few bold mouldings cut in stone, are all that is required.

It is, however, the internal proportions of a chimney shaft, its height and sectional area, that are chiefly of importance.

In fixing on the proper dimensions of the vertical smoke flue, or inside of a chimney shaft, it is a question whether, as is most usual, it should be tapered or diminished in area towards the top, or whether it ought to be parallel, as wide at the top as at the bottom. These questions will be found fully treated of in the article on Chimneys in this Dictionary. But there is another question quite as important as either of the above, and requiring a prior consideration; namely, what are the proper dimensions, height, and area of a chimney shaft most suitable for a steam engine of any given number of horse-power? or, which is nearly the same thing, for burning away a given quantity of coals an hour? This will depend a good deal on the quality of the coals to be used, and the quantity of waste gaseous products arising from their generally imperfect combustion in the furnace, the best Newcastle or Hartley coals, and the best Welsh steam coal, though requiring very different treatment in the furnace, being found equally in practice not to require such large chimneys as the inferior coals of the English Midland and manufacturing districts.

Table I. of the diameters and heights required for chimney shafts of various horse-powers, has been calculated according to the rules given by Péclet; but it has been found in practice that chimneys having dimensions as calculated by these rules will on an average, with good management, do nearly double the work assigned by this table.

Thomas Box, in his Treatise on Heat, gives the following table of the power of chimneys to steam boilers, the flues having a constant length of circuit of 100 ft.; and although this length will evidently be too great for small boilers, the only practical effect it will have will be to make the chimney rather too powerful for such cases; but this is an error on the right side, it being always expedient to allow a margin for unforeseen contingencies, the excess of power being held in check by adjustment of the register or damper. In this table the power of the chimney is given at 25 per cent. of the maximum calculated power, thus allowing a margin of 25 per cent.; thus the maximum power of a round chimney having an internal diameter of 3 ft. 6 in. and a height of 80 ft. will be $\frac{150 \times 4}{3} = 200$ horse-power.

As examples of the actual work accomplished by existing chimney shafts, Table III. affords particulars of three chimneys at Deus Works, Dundee. In No. 1 the draught was not good, on account of only one boiler being connected with the chimney. In No. 2 the furnaces are situate at about the level of the base of the chimney. In No. 3 there is a rise of 63 ft. from the firing level of the first fifteen boilers to the bottom of the chimney shaft, and a rise of 86 ft. from the remaining four boilers; so that the total height from the firing level of the 15 boilers to top of chimney is 225 ft. From both these ranges of boilers the smoke is conveyed to the chimney by a long sloping brick flue or funnel, mostly under ground.

TABLE I.—POWER OF CHIMNEYS TO STEAM BOILERS. PÉCLET.

Horse-power of Chimney.		Assumed Length of Circuit of Flues in Feet.	Height of Chimney in Feet.						
			20	40	60	80	100	125	150
Square.	Round.		Maximum Size of Chimney in Inches.						
10	7·8	45	18·40	14·12	12·95	..	..	..	..
20	16	65	23·30	19·73	18·12	17·07	..	..	..
35	27	85	30·73	26·10	23·83	22·39	..	..	..
50	39	105	36·96	31·17	28·41	26·06	25·45	..	..
75	59	110	..	37·96	34·56	32·39	30·88	..	..
100	78	110	..	..	39·63	37·11	35·35	34·52	..
150	118	110	..	..	48·34	44·19	43·03	41·00	39·57
200	157	110	..	..	57·55	51·95	49·40	47·04	45·38
300	235	120	..	..	..	..	60·23	57·33	55·20
400	315	130	..	..	..	..	..	65·97	63·48
500	390	150	..	..	..	..	..	..	70·85

TABLE II.—POWER OF CHIMNEYS TO STEAM BOILERS. BOX.

Inside Diameter at the Top.		Height of Chimney in feet.											
		40		60		80		100		120		150	
		Round.	Square.	Round.	Square.	Round.	Square.	Round.	Square.	Round.	Square.	Round.	Square.
ft.	in.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1	0	6·4	8·1	..	..	..	..	..	..	..	..	..	..
1	3	10·9	13·9	12·8	16·3	..	..	..	..	..	..	..	..
1	6	16·6	21·0	17·5	24·8	21·7	27·5	..	..	..	..	..	..
1	9	23·5	30·0	27·9	34·2	31·1	40·0	..	..	..	..	..	..
2	0	31·9	41·0	37·3	47·5	42·3	53·8	45·7	58·2	..	..	..	..
2	3	..	..	49·4	62·8	55·3	70·4	60·0	76·4	63·8	81·2	..	..
2	6	..	..	65·3	83·1	70·4	90·0	76·5	97·4	81·0	103·0	85	108
2	9	..	..	78·0	100·0	88·0	112·0	94·9	121·0	101·0	128·0	106	135
3	0	..	..	94·0	123·0	106·0	135·0	114·0	145·0	123·0	157·0	130	165
3	6	..	..	..	..	150·0	191·0	163·0	207·0	175·0	223·0	186	237
4	0	..	..	..	..	202·0	257·0	220·0	280·0	235·0	300·0	252	321
5	0	..	..	..	..	..	..	360·0	458·0	388·0	494·0	415	528
6	0	..	..	..	..	..	..	..	..	577·0	734·0	615	783

TABLE III.—CHIMNEYS AT DEUS WORKS, DUNDEE.

No.	Height above Ground.	Internal Area of Flue.			No. of Boilers.	No. of Furnaces.	Area of Flue for each Boiler.		Consumption of Coal for 60 hours work of all the Engines.	Average Draught of Chimney.
		At Bottom.	At Top.	Contracted at Outlet to			At Bottom.	At Top.		
	ft.	ft.	ft.	ft.			ft.	ft.	tons	
1	102·8	18·06	2·25	1·75	1	1	18·06	1·75	10	·50
2	135·0	49·00	18·06	13·78	7	2	7·00	1·96	75	·75
3	162·0	90·25	36·00	25·00	19	2	4 75	1·31	210	·80

The best form of section for a chimney, as regards its stability, is the circular, next to it the octagonal, and lastly the square form; the force exerted by the wind being twice as great against a square chimney as against a circular one of the same diameter. The square and octagonal forms, however, possess one great advantage over the circular, and that is, that the brick bond is much better and stronger in either of the former than it is in the latter.

A general rule given for the height of chimney shafts is, that if the shaft be square, its height should not exceed ten times the outside diameter at the top of the footings; if octagonal, the height may equal eleven times the lower diameter; while, if circular, it may be as much as twelve times the diameter. This rule, however, does not seem to be very generally followed, as many chimneys exist with heights equalling from fourteen to eighteen diameters. The diameter should decrease in a regular manner, being about one-third less at the top than it is at the bottom.

Table IV. shows the rate of diminution and the proportion of base to height, in a number of large chimney shafts. It will be seen that the proportions vary considerably in different places. Local customs doubtless have their influence, but the special purposes in view have, and ought to have, more influence still. For, as already pointed out, it makes a great difference whether the shaft is to be used for an engine boiler, an iron furnace, or a range of kilns; a flue that would answer perfectly well for one of these might do very badly for either of the others.

Table IV.—Proportions of Chimneys.

Name.	Outside Diameter at Base.		Height above Ground.	Diminution of Width in 10 Feet of Height.	Number of Diameters High.
	ft.	in.	feet	inches	
Townsend's Chemical Works, Glasgow	32	0	454	$4\frac{3}{4}$	$14\frac{1}{5}$ about
St. Rollox, Glasgow	40	6	432	$7\frac{1}{4}$	$10\frac{5}{8}$ „
Messrs. Dobson and Barlow, Bolton, Lancashire ..	42	6	$367\frac{1}{2}$	$10\frac{2}{3}$	$8\frac{5}{8}$ „
Chemical Factory at Barmen, Prussia	18	0	331	$2\frac{1}{2}$	$18\frac{1}{3}$ „
Chimney at Bradford, Yorkshire	20	0	300	$4\frac{1}{3}$	15
Dye Works, Hogen, Prussia	18	6	274	$3\frac{1}{3}$	$14\frac{6}{7}$ about
West Cumberland Iron Company, Workington, No. 1	24	0	250	5	$10\frac{1}{2}$ „
Pontifex's Works, Isle of Dogs	20	6	228	6	$11\frac{1}{8}$ „
Shell Foundry, Woolwich	16	9	224	$5\frac{1}{2}$	$13\frac{3}{8}$ „
Messrs. Gostling's, Northfleet, part fell	22	0	220	6	10
West Cumberland Iron Company, Workington, No. 2	23	0	200	5	$8\frac{2}{3}$ about
Boring Mill, Woolwich	13	1	170	$5\frac{1}{3}$	13
Rocket Buildings, Woolwich	11	6	150	$5\frac{5}{8}$	13
Steam Engine at St. Ouen, France	10	8	132	$5\frac{1}{2}$	12 about
Saw Mill, Woolwich	10	6	130	$5\frac{1}{3}$	12 „
Paper Factory, Woolwich	10	3	120	5	$11\frac{3}{4}$ „

The projection at the head of the chimney, if any, should not exceed three-fourths of the thickness of the brickwork from which it projects; but if it is desired to have a very ornamental projecting chimney-top, precautions must be taken to have a blocking course on the top of sufficient weight to counterbalance any tipping tendencies of the overhanging parts. Very effective chimney-tops may be formed by gradually corbelling out the brickwork in various ways before reaching the top. Hollow terra-cotta copings may be used with advantage, inasmuch as they can be cast to any form, and are lighter than either stone or brick, and are especially suitable where considerable projections are required. Probably the best form of cap for a chimney is one formed of cast iron, with a bold outside moulding; to be cast in sections, and firmly bolted together at the top of the chimney. This effectually prevents all percolation of water through the joints of the brickwork from the top, which, after severe frost, often causes unsightly, if not dangerous, cracks in unprotected shafts.

The proper thicknesses of brickwork for a shaft in a sheltered position need not be so strongly constructed as one which is always exposed to currents of wind, and therefore, in the former case, less thickness of brickwork may be adopted than in the latter. A good rule, given by Molesworth, is to increase the thickness of the shaft, from the top downwards, half a brick in every 25 ft; but this is scarcely ever carried out in very high shafts. We believe the following dimensions to be more in accordance with general practice. Let us suppose a chimney 200 ft. high, and square on plan, the width of the side at the top of the footings being 10 ft., and the width of the top 6 ft. 6 in., or say 6 ft. Then commencing at the top, and working downwards,

The first 25 ft. should be .. .. 1 brick thick.
„ next 25 „ „ .. .. $1\frac{1}{2}$ „
„ „ 30 „ „ .. .. 2 „
„ „ 30 „ „ .. .. $2\frac{1}{2}$ „
„ „ 35 „ „ .. .. 3 „
„ „ 35 „ „ .. .. $3\frac{1}{2}$ „
and the bottom 20 „ „ .. .. 4 „

Sometimes the top 5 or 6 ft. is only half a brick thick, but this does away with the bond, which is one of the most essential things in all brickwork.

The height of the footings should be at least 10 courses of bricks, the bottom course being 8 bricks in width; this will give a 2 brick set-off on each side of the wall, and if the courses be double, each set-off will be about $3\frac{1}{2}$ in. in width. The concrete foundation should be 20 ft. square on plan, with a depth of 7 ft. A section of the base of this chimney is shown in Fig. 821. The width at top of the shaft being 6 ft. externally, and the walls 9 in. thick, the internal width will be 4 ft. 6 in. When the internal width of the top of a chimney exceeds 4 ft. 6 in., it is the general practice to make the top 25 ft. $1\frac{1}{2}$ brick in thickness instead of 1 brick; and as accidents have occurred where this rule has not been followed, it will evidently be advisable to adhere to it until such time as science shall have provided the engineer with a better.

Table V. shows how much practice differs with respect to the thickness of brickwork for shafts; it affords details of three chimneys at Woolwich, and, for the sake of additional comparison, one chimney at Manchester.

TABLE V.—SECTIONS OF CHIMNEY SHAFTS.

Name of Place.	Height above Ground Line.	Number of Bricks Thick.								Width at Base.	Width at Top.	Observations.
		4½	4	3½	3	2½	2	1½	1			
	feet	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	
Woolwich—												
Royal Arsenal ..	120½	..	..	..	16 6	25 3	25 3	28 3	28 3	10 9	4 9	Scaffold erected independent of shaft, and without a putlog hole. The top 28 ft. 3 in. in cement.
Gun Factory ..	170	..	..	..	30 0	50 0	30 0	30 0	30 0	18 9	5 6	First 30 ft. is square on plan, the remaining 140 ft. octagonal on plan.
Shell Foundry ..	223¾	8 9	31 6	31 6	31 6	31 6	31 6	31 6	36 0	20 0	6 6	Square. Top 9 ft. built in cement.
Coltness Iron Works Manchester.	210	35 0	40 0	..	50 0	50 0	..	45 0	..	18 6	10 6	Firebrick lining 25 ft. high and 10 in. thick.

The building of a high chimney shaft is a work special in all its conditions, and cannot be compared with ordinary walling.

All shafts should be erected during the summer, operations being commenced as soon as possible after the disappearance of frost. If, however, through unavoidable circumstances, a shaft has to be erected during the winter, building operations must be discontinued on the least appearance of frost, the surface being carefully covered to prevent injurious effects. Brickwork laid in frosty weather, or between the joints of which moisture has been allowed to percolate, and which afterwards becomes frozen, is almost certain to be destroyed, when a thaw sets in, by the consequent swelling of the mortar.

It is not advisable to erect a chimney shaft too quickly, as the weight on the lower portion is constantly increasing, and would be liable to cause a slipping in the mass, if the mortar were not allowed time to properly set. As the setting of the mortar depends on the state of the weather, and on the quality of the lime or cement employed, the rate of progress in the height of the chimney, which can be allowed with safety, will depend upon the same two causes. The rate generally followed is from 2 ft. to 2 ft. 6 in. a working day, according to the size and height of the shaft. In Manchester and some of the Lancashire towns, it is the custom in erecting very high shafts to carry them up to half their height, and then allow them to stand for six months to consolidate, at the expiration of which time the rest of the work is completed; but this is necessary only in the case of very high and large shafts, which could not be completed in a single season.

The strength of a shaft depends, in a great measure, upon the materials employed in its construction and the quality of the workmanship. A shaft should not be tied to any existing building or wall, but its own proportions should secure its stability; neither should any woodwork be fixed in or to it.

Brickwork built with Portland or Roman cement, requires a weight of about 30 tons a superficial foot to produce fracture from compression; and when built with blue lias mortar, thoroughly set, it requires about 29 tons, but nothing like this weight is ever reached in chimney shafts. In proof of the strength of brickwork, we may state that there is a brick chimney at Manchester 410 ft. high, one at Wigan 420 ft. high, and another at Warrington 440 ft. high, while the shaft at Townsend's Chemical Works, Glasgow, is 454 ft. in height; and therefore, provided the bricks be sound and good, there need be no fear as to their strength, but all precautions will have to be taken respecting the quality of the mortar used.

The bricks used should be picked stocks, hard and sound, with sharp, square edges, thoroughly well burnt, and of a uniform thickness. When any new form of bricks or terra-cotta ornaments are used, they must be so made as to work in bond, and in course, with common bricks; for it must be remembered that the bricklayer has to use them, and that, consequently, if they are of a complicated make, it is more than probable that the proper fixing of them will not be attended to.

The bricks should be well wetted with water just previous to being laid, in order to prevent their absorbing the moisture of the mortar too rapidly. The joints of the brickwork should be well flushed up with mortar every course; this is much to be preferred to the ordinary method of grouting every two or three courses, grouting being fluid mortar, which as the water dries out becomes porous, and consequently possesses but little adhesive power. The work should be bevelled and plumbed every 3 ft. or oftener, in order that the batter may be preserved perfectly regular.

Furnace shafts should be lined with firebrick to the extent of 10 ft. at the least above the opening from the furnace; the lining should not be tied to or made to support the brickwork of the shaft, but be constructed independent of it, so that the lining may be cut out, taken away, and replaced, without endangering the structure. Moreover, a space should be left between the two of at least half an inch, to permit the interior firebrick lining to expand without disturbing the main exterior walls.

Welsh Dinas brick, consisting of nearly pure silica, is the only material of those practically available on a large scale, that has been found to resist the intense heat at which steel-melting furnaces are worked; but though this material withstands perfectly the temperature required for the fusion of the mildest steel, yet it will be melted easily if the furnace be pushed to a still higher heat. As the gas flame is quite free from the suspended dust, which is always carried over from the fuel by the keen draught of an ordinary furnace, the brickwork exposed to it is not fluxed on the surface, and gradually cut away, but fails, if at all, only through absolute softening and fusion throughout its mass. A Stourbridge brick, for example, after being exposed for a few hours to the heat of the steel-melting furnace, remains quite sharp on the edges, and is little altered even in colour; but it is so thoroughly softened by the intense heat that, on attempting to take it out, the tongs press into it and almost meet, and it is often pulled in two, the half-fused material drawing out in long strings.

Ordinary mortar is formed of 1 part by measure of Dorking greystone lime to 3 parts of sharp river sand. When it is desirable to have a quick-setting mortar of great strength, it is customary to use Portland cement and sand, in the proportion of 1 part by measure of cement to 2 parts of sand. Cement should not be used new, as it improves with age, if kept from moisture; while, if used new, it is apt to expand. Lime and cement should not be mixed to form mortar, as the lime hardens slowly and the cement quickly. The crushing weight of Portland cement is very great; at the expiration of six months, after being made into a mortar of 1 part of cement to 2 of sand, it requires 1 ton a sq. in. to crush it, and about five-eighths of the crushing weight to produce the first crack.

For the making of ordinary mortar, Dorking greystone lime is the best; but where a more hydraulic lime is thought desirable, blue lias lime is generally used. The more hydraulic a lime, the less sand it will take up when made into mortar, blue lias lime being completely spoilt by an excess of sand; it requires but little water to slake it, and after being wetted it should be made into a heap and covered with sand. If previously ground, a good practice is to spread it under a shed some little time before it is required for use, and to slake it by the moisture of the atmosphere. Blue lias commences to set in ten to fifteen minutes after being made into mortar.

All tall structures, as we have already remarked, should depend as much as possible on the cohesion of the materials, and gravity, for stability; and when iron bands, iron cramps, or stays are used, care must be taken so to apply the metal as to run the least risk from contraction or expansion. It is customary in erecting chimney shafts to use hoop-iron bond every ten courses in height, one strip for every half-brick in thickness of wall. The iron should be well tarred and afterwards covered with sand, to give a rough surface to which the mortar may readily adhere. In footings, or in thick walls exposed to great strains, strips of hoop-iron should be laid diagonally, interlacing with those laid in a longitudinal direction.

The depth of the foundation in compressible ground ought not to be less than one-eighth the intended height above ground, and oftentimes one-sixth would be better. The base of the foundation is made at least one-half longer than the base of the shaft, and it is placed as low as the base of the foundation of any adjoining wall or building. In doubtful foundations it should be placed lower than the foundations of adjoining buildings; for where this is not the case there is risk of accident to the shaft, as the smallest irregular settlement would cause a break in the structure. An unequal foundation, part soft and part hard, is bad; and a compressible foundation of clay marl, or shale, unsafe. It is therefore often necessary to enlarge the area by spreading the footings, or by using inverted arches to distribute the weight.

The following particulars will show the amount of care and caution which is required to be taken when erecting a chimney shaft near to any deep excavations. At the London Docks a high chimney which was erected near the pumping engine house, stood on a square of concrete of considerable thickness, the pumping engine itself resting on beech-piling, and was adjacent both to the pumping well, which is 18 ft. in diameter, and to the excavation for the lower dock. A plumb-bob was therefore left suspended in the chimney, which would give warning of any inclination. Some time after the chimney was built, the plumb-bob showed that the shaft had inclined several inches towards the excavation. A quantity of limestone was therefore stacked round the base of the chimney, on the opposite side to the inclination, and this brought the shaft back to the perpendicular; but had the shaft not been brought back to the upright, the first gale of wind would probably have blown it down.

When concrete is employed to form a foundation, it should be spread over such an area that it may be sloped at an angle of 45° from the outside of the footings of the walls, down to the bottom of the foundation; and of such a thickness that it will not be liable to crack under the pressure to be put upon it. The proper thickness will of course depend upon the nature of the ground; whether rock, gravel, clay, or sand. As a general rule, a concrete foundation of not less than 1 ft. 6 in. in thickness is adopted for shafts not exceeding 40 ft. in height; an extra 4 in. being added for every additional 10 ft. According to this rule, a shaft 100 ft. high would have a concrete foundation 3 ft. 6 in. thick; and for one 200 ft. high, the foundation would be about 7 ft. thick.

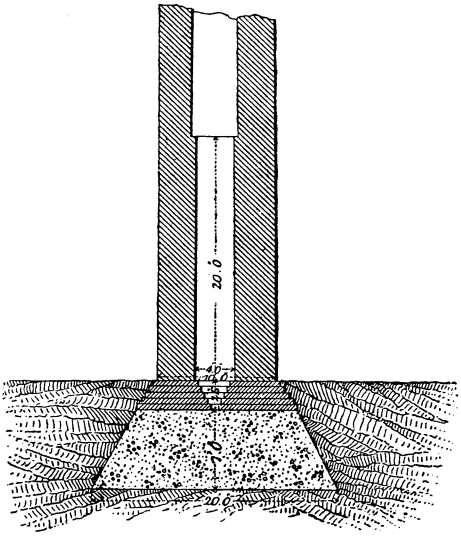
Care must be taken in putting in a concrete foundation, not to carry on the work during frosty weather, as then a layer of concrete does not become thoroughly incorporated with the previous layer. Neither does proper mixture take place unless the meeting surfaces are kept rough, and free from sand; but by sweeping off all sand, and, if necessary, picking the face in furrows, and by breaking joint with the layers, water will not run through the mass.

When concrete is not exposed to the direct action of water, it may be made with Dorking greystone lime, in the proportion of 1 of ground lime to 8 of ballast. This lime carries more sand than lias, and is but feebly hydraulic. If the soil is wet, or the shaft is of great weight, the concrete should be made with hydraulic lime. With moderate hydraulic and common limes there will be an expansion of the mixed concrete, consequent on the slaking; and this expansion should generally be allowed for in preparing the site for the concrete, as it is seldom that the slaking is wholly accomplished before the concrete is laid. Blue lias concrete will, in hot weather, expand as much as one-thirtieth of its bulk, and in frosty weather, about one-fiftieth; when the expansion exceeds one-thirtieth, the concrete is too rich in lime.

As a mass of lime concrete sets slowly, and is subject to expansion in setting, the modern practice in all important works is to use Portland cement instead of lime, as the former does not expand, and the concrete produced is also stronger. According to the result of a series of experiments, made by Crawford, for the purpose of ascertaining the best description of concrete to be placed round the foundations of the river piers at Görlitz, Prussia, the proportions most suitable for yielding a quick-setting hard concrete were found to be as follows: 22 parts of cement, 22 of sand, and 56 of stones broken to pass through a 2-in. ring.

The footing is an enlarged portion of the wall, Fig. 281, for the purpose of distributing the weight over the foundation; it is properly a portion of the wall and not of the foundation, though it is not always easy to draw the line between them. The size of the footings and the mode of forming the increase to the thickness of the wall, will depend upon circumstances and the materials employed. For brick footings the projection of the bottom of the footing, on each side, should be at least equal to one-half of the thickness of the wall at its base; the diminution in width of the footing should be made by regular insets, and its height from top of foundation to base of wall, at the least equal to one-half of the thickness of the wall at its base. Applying this rule to the case of a shaft having walls, at its base, 2½ bricks thick, then the bottom course of the footing will be five bricks thick, that is to say, 2½ bricks under walls and a projection of 1¼ brick on each side. Two-and-a-half bricks being about 22 in. in length, one-half of this length, namely, 11 in., will be the height from bottom to top of footings, or say four courses of bricks, with ¼ brick inset on each side of wall to each course. When a shaft is to be over 100 ft. high, increase the height of the footings, making it equal the thickness of the wall at its base. By this means the insets may be made double with less chance of splitting, and the weight more gradually distributed over the concrete foundation.

821.



In erecting a chimney shaft, especially when tall, the scaffolding should be carried up without a putlog hole in the shaft; that is, it should be perfectly independent, so as not to interfere with regular settlement. This can be managed by cross bracing on each side of the scaffolding, and angle ties to steady the whole. Chimney shafts when of sufficiently large diameter, are generally erected without the aid of exterior scaffolding, the workman supporting himself upon a platform or staging constructed upon supports fixed on the inside of the chimney. Horizontal iron bars are often built into the inside, they are placed about 18 in. apart, and form a kind of ladder by means of which a workman can ascend a shaft to execute repairs.

Lightning rods should be made of the very best conducting material, and of a size sufficient to carry off the heaviest discharge that is ever likely to fall upon them. The only two conducting metals which can be dealt with in practice, are copper and iron. With regard to the relative conducting value of copper and iron, it was formerly considered that if a rod of copper of given size be found to be sufficient, then an iron rod, to be equally safe, ought to have eight times the sectional area of the former, but Brough has proved that the comparative sectional dimensions need only be as 8 to 3. A bar of metal in the form of a flat ribbon has been recommended from purely mechanical reasons, because in this form it is more easily bent, more conveniently attached to the building, and is less conspicuous than when in any other form.

The chief conditions to be observed in a lightning conductor are, that it shall be of sufficient sectional area, that it shall be continuous, and that it shall make good earth contact. It is upon the perfection of this ground connection that the value of the lightning rod mainly depends. If this be defective, no other good features can possibly make up for it.

The end of the rod should be made to terminate in a layer of soil that is permanently wet, and it should expose to this soil as large a surface as possible.

As it is important that the end of the rod should be in wet, moist earth, it is advisable to sink the earth contact of the lightning rod when the foundations are being put in. A short portion of the stem may be allowed to rise above the ground, and the conductor attached subsequently. Ground rods should have two or more branches penetrating the earth, and should extend below the foundation walls. Where it is difficult to reach moist earth, the rods should be embedded in charcoal or coke.

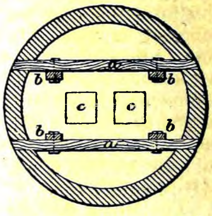
The lightning rod should be attached directly to the shaft, staples of stout wire being generally used for this purpose; the top of the rod need project but slightly above the top of the shaft.

When a shaft has fallen from the perpendicular, through unequal subsidence in the foundation or other cause, it may generally be restored to an upright position by sawing back, the method of performing which will be best understood from the following account of the straightening of the Townsend chimney shaft;—

This chimney was, in September 1859, shortly before its completion, struck by a gale from the north-east, by which it was deflected 7 ft. 9 in. out of the perpendicular, and was several feet less in height than before it swayed; but when brought back to the perpendicular it regained its original height. The deflection began at about 100 to 150 ft. from the ground, so that the foundation and heaviest portion remained firm; but had not the process of sawing been commenced promptly and continued vigorously, the chimney would have fallen; for during the earlier part of the sawing back the deflection was observed to be increasing, but as the operations progressed the deflection was checked, and the chimney gradually came back to its perpendicular position. The sawing back was performed by ten men working in relays, four at a time sawing, and two pouring water on the saws; the work being carried on from the inside on the original scaffolding, which had not been removed. Holes were first punched through the sides to admit the saws, which were wrought alternately in each direction at the same joint on the side opposite the inclination, so that the chimney was brought back in a slightly oscillating manner. These saw-cuts were made at twelve different heights, namely, at 41 ft., 81 ft., 121 ft., 151 ft., 171 ft., 189 ft., 209 ft., 228 ft., 240 ft., 255 ft., 277 ft., and at 326 ft. above the ground line. The men discovered when they were gaining by the saws getting tightened by the superincumbent weight.

The accident to this shaft was due not only to the action of the gale, but also in a great measure to the manner in which the scaffolding had been erected, no provision having been made, to allow of its yielding to the pressure which might be caused by any slight settling down in the mass of the chimney, and consequently the pressure which was thrown by the wind on the lee side of the stalk, the mortar of which had not become solidified, was too great for the scaffolding to bear, and caused the splice of one of the uprights to give way. The construction of this scaffolding is shown in Fig. 822; *b* are the uprights; *a* thick planks which were bolted into the uprights and extended through the walls on each side; these planks, which formed the scaffolding, were placed about 5 or 6 ft. apart vertically, and were tightly built into the walling, but had a little space been left over each, the stalk would probably have subsided uniformly, and withstood the gale; but this error in its construction was not observed until it was too late to remedy it. *c* are the hutches for raising men and materials, one ascending and the other descending.

822.



The following is an account of the method adopted for straightening the lofty chimney shaft at Matthews and Son's Chemical Works, at Pitchcombe, Gloucestershire, which had fallen considerably out of the perpendicular, but which was restored to its original position by a somewhat novel process. The erection of a new stack would probably have cost something like 800*l.*, whereas this was straightened at about a tenth of that cost, and is now stated to be in as good a condition as a new one.

This shaft is 132 ft. high, and was built in 1862. It had gradually fallen from its upright position, and when tested in 1875 it was found to be 3 ft. 10 in. out of the perpendicular. H. J. Taylor, of Nailsworth, undertook to restore it to its original position by a process requiring no scaffolding, and he accordingly commenced operations, assisted by three workmen. The chimney is of an octagonal shape, and the means adopted for straightening it, was to cut out one course of bricks from five of the sides, and to insert a thinner course in their place, and then let the chimney fall back upon the latter and so pull itself upright. For this purpose a platform was erected about 40 ft. from the base, and the chimney, which at this point was about 2 ft. in thickness, was cut through by means of hammers and chisels. As the bricks were removed from each side, a thinner course was substituted, and the intervening spaces were filled with iron wedges. This work lasted for about three weeks, during which time the weather was most unfavourable; the chimney, however, stood through it all, and when everything was in readiness, the wedges were withdrawn and the stack was brought to within an inch or two of its perpendicular position. It was calculated that $\frac{1}{4}$ in. would bring over the stack 7 in. at the top, so that it had to be let down about $1\frac{1}{2}$ in., and had this calculation been exceeded by $\frac{1}{8}$ in., the stack would have been brought over too far.

After the sudden accident to the top of the Northfleet chimney, which occurred on October 2, 1873, about 160 ft. still remained standing. The upper portion of this length was in a shattered and dangerous condition, the walls having been cracked, as it appears, by the fall of large quantities of brickwork down the inside of the chimney, where they struck on the series of horizontal timbers which still remained in the places where they had been used to support the scaffolds. As each timber was struck, it doubtless bent with the blow, and the pressure of its ends against the brickwork, combined with the violent jarring produced by the fall, had given rise at many points to small but easily perceptible fissures in the walls. The lower part of the shaft, as far as could be ascertained, was sound, and it was therefore proposed, if possible, first to throw down the walls as far as they were in a dangerous state, then to take down the slightly injured part by scaffolding, as before, from the inside, and finally to begin building again from the sound part towards the bottom. Charges of compressed guncotton were used, and were electrically exploded in the interior of the chimney. The first did not prove powerful enough to be of much service; a somewhat larger charge was then exploded higher up the shaft, and though this proved insufficient to throw down the apparently dangerous portion, it rent the walls from top to bottom; here was then no object in leaving any part of the work standing, and a third skilfully proportioned charge was fired, which caused the whole structure, with the exception of 30 or 40 ft. at the base, to sink down slowly and almost vertically, into a heap of ruins. No injury of any consequence was done to the surrounding buildings.

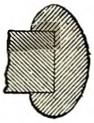
It is sometimes necessary to take down a shaft in a crowded neighbourhood, where it is impossible to loosen the bottom and let it fall. In such cases a scaffold is erected and the shaft taken down piecemeal. An ingenious arrangement for facilitating the taking down of an old chimney shaft, was employed a few years ago at Gilkes, Wilson, Pease and Co.'s works, Middlesborough.

An air-tight iron box was placed at the bottom of the chimney, this box being fitted with an air-tight door, mounted on hinges and closing on an indiarubber face against which it was tightened by a wedge. A wooden spout was then fixed on to the top of the box and carried up to the top of the chimney; this spout was $3\frac{1}{2}$ in. by 5 in. inside, and was made of planks $1\frac{1}{8}$ in. thick, well nailed together, with a little white lead on the edges, thus making the spout perfectly air-tight. The spout was made in about 12-ft. lengths, joined together by cast-iron sockets or shoes, and caulked round with tarred yarn. A few stays were put inside the chimney to keep the spout steady, and steps were nailed upon it by which the men could ascend. The spout being internally ½ in. larger than the width and thickness of a brick, the bricks were partially cushioned in their fall and arrived at the bottom without any damage, As soon as the box was full, the man at the bottom signalled to stop, and then opened the air-tight door and removed the bricks which had come down; this being done, he again shut the door and signalled to go on again. The man on the top lowered his own scaffold, and as the spout got too high, cut a piece off with a saw. If there was much mortar adhering to the bricks, it was knocked off before putting the latter into the spout, and it was allowed with any small pieces to fall inside the chimney. The plan is certainly simple, and may be employed with advantage in many places.

The following is a description of the Townsend chimney, at Port Dundas, Glasgow, built by Robert Corbett, of Glasgow.

The total height of the shaft from foundation to top of coping is 468 ft., and from ground level to summit 454 ft.; the external diameter at the ground line being 32 ft., and at the top of cope 12 ft. 8 in. The cope is of vitrified tile, it was made expressly for the chimney, each piece being about 9 in. wide by 3 in. thick; it is flanged over the wall of the shaft in the manner shown in Fig. 823, and it is cemented at the joints with Portland cement.

823.



The foundation, which consists of thirty courses of brick on edge, the lowest course being 47 ft., and the topmost course 32 ft. in diameter, was commenced on July 30, 1857, and it was finished on August 20 of the same year. No piles were used in this foundation, as the shaft is built on the blue till or clay, which is as solid and compact as rock. On the completion of the foundation, the erection of the shaft was proceeded with until November 11, which closed the first season; but the work was suspended during the interval between September 3 and October 5. The second season commenced on June 10, 1858, and closed on October 16; at which date the stalk had attained a height of 228 ft. The third and last season commenced on June 3, 1859, and the coping was laid on October 6 of the same year; but the work had been suspended from September 15 to October 5, in consequence of the chimney swaying; and during this interval it was restored by twelve cuttings with saws on the side opposite to the inclination, in the manner previously described.

The inside lining or cone is of 9-in. firebrick, and is about 60 ft. in height; it is built distinct from the chimney proper, with an air-space between, and is covered on the top to prevent dust falling in, but it is built with open work in the upper four courses, so as to allow of air passing into the chimney.

The size of the bricks used in the construction of this chimney was 10 by 4 by 3½ in.; they were made specially for this shaft, and the number consumed was as follows;—

Common bricks in chimney	1,142,532
Composition and firebricks in cone	157,468
Total..	1,300,000

The bricklayers' time was:—

In 1857—316 days of 10 hours each.
„ 1858—431½ „ „
„ 1859—423½ „ „

Giving a total of 1171 days' time occupied in building the chimney, or an average of 1110 bricks built by each bricklayer a day of 10 hours.

Besides this number of bricks used in the chimney, there were also 100,000 used in constructing the flues; the total number of bricks laid in chimney and flues being 1,400,000, the weight of which, at 5 tons a thousand, equals 7000 tons.

Iron hoops were built into the thickness of the shaft at intervals of 25 ft. in height; at the bottom they were put at a distance of 9 in. from the outer surface of the walling, and at the top at 4½ in. from the surface.

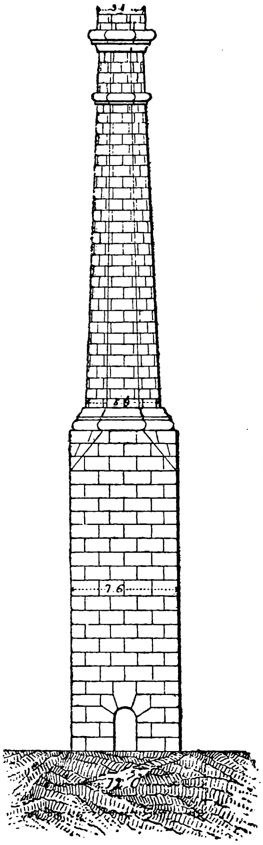
The thickness of the wall of this chimney varies as follows; commencing at the ground level;—

The	First Section,	30 ft.	in height, is	5 ft.	7 in.	thick.
„	Second „	30 ft.	„	5 ft.	2 in.	„
„	Third „	30 ft.	„	4 ft.	10 in.	„
„	Fourth „	40 ft.	„	4 ft.	5 in.	„
„	Fifth „	40 ft.	„	4 ft.	0 in.	„
„	Sixth „	40 ft.	„	3 ft.	7 in.	„
„	Seventh „	40 ft.	„	3 ft.	2 in.	„
„	Eighth „	40 ft.	„	2 ft.	9 in.	„
„	Ninth „	40 ft.	„	2 ft.	4 in.	„
„	Tenth „	52 ft.	„	1 ft.	11 in.	„
„	Eleventh „	52 ft.	„	1 ft.	7 in.	„
„	Twelfth „	20 ft.	„	1 ft.	2 in.	„
	Total	454 ft. from ground line.				

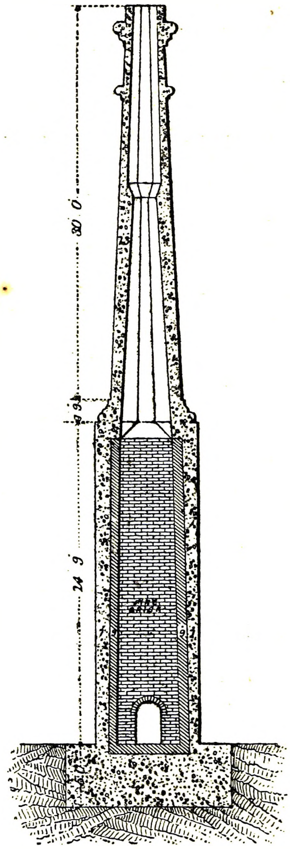
The height originally contemplated for the chimney was 450 ft.; but when about 350 ft. up, it was proposed to add about 35 ft. to the original height, making the total height 485 ft.; hence the increased height of the tenth and eleventh sections; on the completion of the eleventh section, however, this idea was abandoned, and therefore only 20 ft. were added of the last thickness.

The concrete chimney shaft, Figs. 824 and 825, was erected in 1873 for the River Wear Commissioners at their chain testing works, at the South Docks, Sunderland. The shaft is carried up square until it is well clear of the roof of the testing house, the outside dimensions being 7 ft. 6 in. by 7 ft. 6 in. by 22 ft. 3 in. in height, and the interior dimensions 4 ft. square; the whole of this portion is lined with 9-in. firebrick. At this level the corners are gradually taken off the square base until, at the height of 24 ft. 9 in. above the surface of the ground, it is brought into the octagonal form of the tapering portion of the chimney. This octagonal and tapering portion of the shaft, in which the difficulty of the work chiefly centred, was moulded in the following manner. Panels 3 ft. in height, Figs. 826 and 827, were formed of $\frac{3}{4}$-in. boards, hinged together in pairs at their outer edges, and these panels were so proportioned that the lines of their outer edges, when produced, came into one point in the centre at half the height of this section of the chimney; the intermediate space being made up by a wedge piece. These panels were placed on the inside and outside of the chimney, and the concrete poured in between them. After the concrete had set, the wedge pieces were taken out and reduced, to meet the decrease in size on the next lift due to the batter; the amount of this reduction being just sufficient to take off, on one side of the wedge piece, the holes for the stud bolts, which connected it to the upright members of the frame. When the stalk of the chimney had been carried up to the half of its full height, the panels were sufficiently reduced to admit a second set of intermediate wedges, of exactly the same dimensions as those introduced at the level of the base mould, thus bringing the inner edges of the reduced panels into one point at the centre of the top of the chimney, in a manner similar to that in which, at their original dimensions, they had been brought together at half its height, and so affording a test of the accuracy of the work; for the uprights being 6 ft. in length, and always being moved with the panels, which were one-half of that height, the former had a continual hold of 3 ft. on the completed portion of the work, and by this arrangement regularity in line was ensured. The chimney when completed was stuccoed with cement, and drawn in courses to imitate stone. The concrete was mixed in the proportion of one part of Portland cement to five of gravel.

824.



825.



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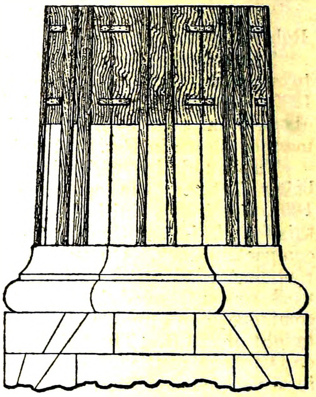
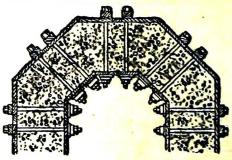
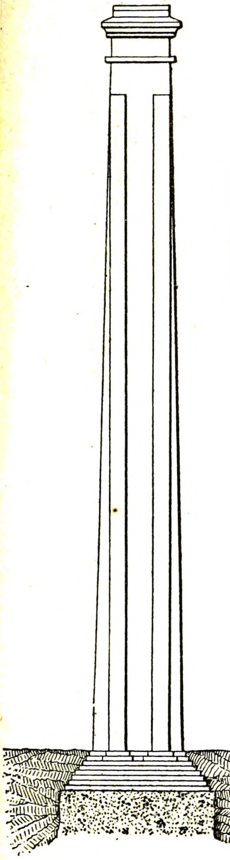


827.



The chimney shaft, Figs. 828 to 831, was erected in 1862 at the works of the South Metropolitan Gas Company, London. Fig. 828 is an elevation, Fig. 829 a section, Fig. 830 a sectional plan at the ground level, and Fig. 831 a cross section at the level of the top of the buttresses. The shaft is constructed with a square flue, 5 ft. in diameter, the interior being straight and parallel from bottom to top. The walls of this flue are only 14 in. in thickness throughout the whole of their height, the necessary strength and stability being given to the chimney by means of buttresses, which are built on each of the four sides. The chimney is lined with firebrick from bottom to top, the firebricks being built in with the stocks, in alternate courses of headers and stretchers, so that this lining is alternately 9 in. and 4½ in. in thickness. The number of bricks used in the construction of the shaft was about 80,000; its total height above the ground level being

828.



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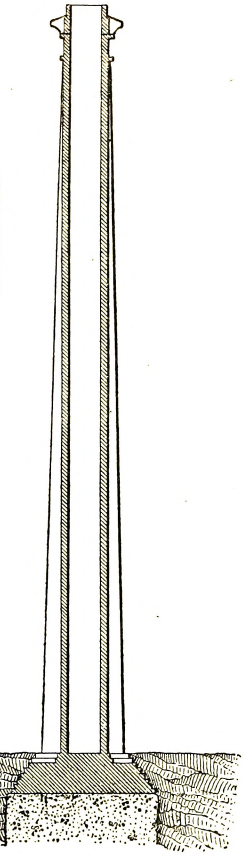

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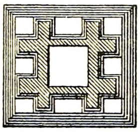

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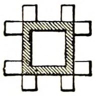

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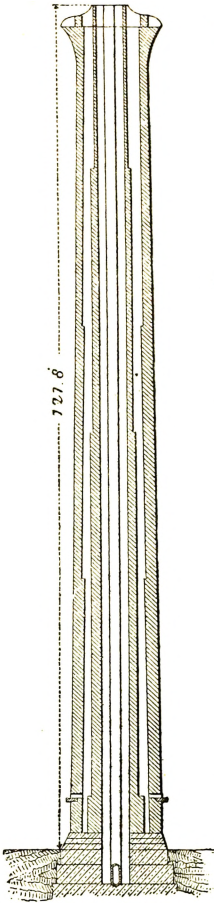

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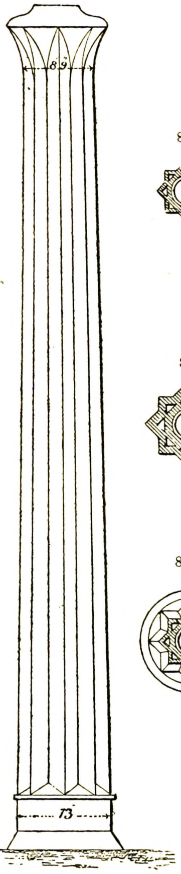

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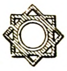
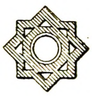
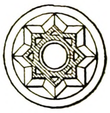


835.



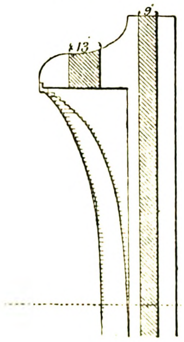
836.



108 ft. The cap is of cast iron, and weighs 2 tons; and the top of the chimney is finished with a copper rim one-eighth of an inch thick.

Another design of chimney shaft is Figs. 832 to 837. This is erected at the West Philadelphia Workshops of the Pennsylvanian Railroad, U.S.; it is 121 ft. 8 in. in height above the ground level, and is built of brick upon a stone foundation, the cap being of cast iron. In plan the shaft is an eight-pointed star, resting upon a circular base; the points of the star are built hollow, and are provided with air-openings at the top and bottom of the chimney. An inner lining, 4½ in. thick, runs from bottom to top of the flue, but is not bonded to the rest of the brickwork; and this lining to about a fourth of its height is of firebrick. Fig. 832 is an elevation, Fig. 833 a sectional elevation, Fig. 834 a plan at top of circular base, Fig. 835 a section at about 20 ft. above the ground level, Fig. 836 a section just below the springing of the cap, and Fig. 837 an enlarged section of the cap and corbelling. The diameter of this shaft is at its base 13 ft.; at the springing of the cap, the corbelling of which commences at 102 ft. above the ground level, the diameter is 8 ft. 9 in., and the extreme diameter of the cap 14 ft., the interior diameter of the flue, the sides of which are parallel and perpendicular, being 4 ft.

837.



COAL CLEANSING AND WASHING.

The proportion of large coal to small which is obtained from any seam, varies, under similar conditions of working, in inverse proportion to its hardness; with hard-steam or anthracite, this proportion will generally be small, but with the rich bituminous coals, the proportion will often be as high as 50 per cent. of small, while in the Belgium coal-fields, where the coals are very soft, the proportion of large averages only about 40 per cent. and often falls as low as 30 per cent. of the total quantity holed, thus giving an average of 60 to 70 per cent. of small.

The small coal when clean is chemically and intrinsically as valuable as an article of fuel, as the large, the only difference being in the mechanical conditions under which it exists. But when sent to bank this duff or slack, as it is technically called, through carelessness in loading the tubs and from other unavoidable causes, generally contains a large percentage of impurities, such as shales, iron pyrites, carbonate of lime, and carbonate of magnesia, which render it totally unfit for use, either in blast furnaces or other metallurgical operations, or for the manufacture of coke; for all of which purposes it is required that the coal shall be of as pure a quality as possible.

Several plans have from time to time been devised for effecting the separation of these impurities from the coal; but most of them have failed to accomplish the object sufficiently well, without incurring a considerable waste of fine coal, heavy cost in wages, and the fouling of a large quantity of water. This last objection has been a very serious one, and in many places, on this account alone, coal washing has been abandoned, consequent on legal proceedings having been taken against colliery proprietors for polluting the streams; but by filtration this objection has to a great extent been overcome.

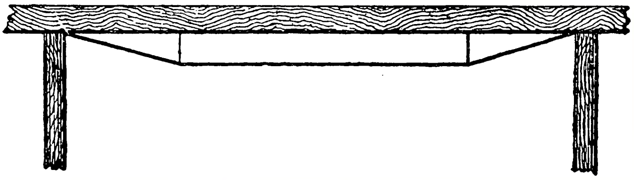
The oldest method of coal washing, which is still largely employed in the Lancashire, Yorkshire, and other north of England districts, is the sloping trough, which consists of a wooden trough 200 to 500 ft. in length, and varying in width, in different districts, from 18 in. to 3 or 4 ft., and having an inclination ranging from 1 in 70 to 1 in 48. The coal to be washed is fed into the upper end, and is gradually carried forward by the action of a continuous stream of water. At intervals of 10 to 30 ft. steps or traps, about 3 or 4 in. high, are placed across the bottom of the trough, to intercept the pyrites, shale, and waste, which, by their superior gravity, fall to the floor of the trough, the specific weight of shale being 2·7205, and that of coal but 1·4696, and when these traps get filled up, a slide or door immediately underneath is opened, and the impurities drop out. When the coal reaches the bottom end of the shoot it passes over a perforated plate of copper or zinc, through which the greater part of the water passes, carrying with it some of the finer particles of the coal. From this plate the coal is delivered into tubs, having perforated bottoms, in order to allow as much of the water as possible to drain away. This water, together with that which drains through the plate at the end of the trough, flows into catch ponds or settling pools, in which the fine coal becomes deposited, and from which it is periodically removed, and conveyed to the coke ovens. These ponds are generally from 20 to 30 ft. square, and about 4 ft. in depth. Sometimes, instead of the traps, square holes are left in the bottom of the trough, and below these openings boxes are constructed, in which the impurities collect in the same manner that they do behind the steps, and from which they are removed by a similar contrivance.

The length of trough over which it will be necessary to pass the coal, in order to thoroughly wash it, as also the amount of inclination which may be given to the trough, will depend upon the nature of the impurities; that is, upon the difference between their specific gravity and that of the coal. For instance, when there is a large proportion of shale, it will require to be passed over a long trough having a very low angle, but when the impurities consist mainly of iron pyrites, the length of the trough may be considerably reduced, and the angle of its inclination increased; so that a given quantity of the latter coal would be cleaned in a much shorter time than the same quantity of the former.

The coal-washing apparatus employed at the Ince Hall Colliery is constructed on these principles, and consists of a line of spouts attached at one end to the slack or duff hopper of the nut-screening apparatus, which are continued to each row of coke ovens, or if necessary to each oven. By means of valves worked by an attendant, who is stationed near the coke ovens, water and slack are admitted, together or separately, as required, into the spouts at the end attached to the nut-screen. The distance from the screens to the ovens is about 600 ft., but this distance could have been doubled with advantage.

The spouts are arranged as follows;—From the screen for a distance of 275 ft. the trough is about 10 in. by 10 in. inside, and is fixed with a fall towards the ovens of 1 in 18; the next 40 ft. is 10 in. by 10 in. with a fall of 1 in 24; and the next 70 ft., 23 in. broad by 10 in. deep and falling 1 in 24. These spouts are supported by single upright poles which are placed at intervals of about 60 ft. apart, the centre of each length of trough being held up level by wire-rope suspenders or guys, reaching from pole to pole, in the manner shown in Fig. 838. At a point 326 ft. from the slack-screen there is a valve in the bottom of the trough, which when opened, the slack being previously shut off at the screen, allows all the dirt and refuse that may be deposited in the spout down to this point, to fall into the dirt waggon beneath. Fifteen feet lower down there is a dam formed of a piece of wood 3 in. deep, which arrests the progress of any of the lighter particles of dirt which do not settle higher up the spout. When the dirt collected behind this dam reaches to the top of the piece of wood, a second and afterwards a third piece, each of the same depth as the first, is inserted, and when the accumulation of refuse attains this depth, a valve in the bottom of the spout is opened and it is allowed to fall into the dirt waggon which is placed beneath, and the two upper pieces of wood are removed from the dam. At a point 24 ft. lower there is again a dam, formed by a similar piece of wood, which secures any stray pieces of dirt that may have escaped the obstructions higher up; and 31 ft. nearer the ovens there is another loose dam 2½ in. high, and at this latter point there is a valve to let out the dirt from both these dams.

838.



The quantity of Arley Mine slack washed daily is 120 tons, yielding about 6 per cent. of refuse; the quantity of water required being about 80 to 90 gallons a minute. The attendance to the washing department costs three shillings a day, or three-tenths of a penny a ton on the slack.

The advantages of this mode of washing small coal are simplicity of arrangement, the chief requisite being a copious supply of water, economy in first outlay, and in cost of working and upholding, the spouts, dams, and valves being simple in design and not difficult to keep in order. There is also a considerable economy in the carriage of the slack by water as compared with ordinary modes of transit, the difference in this case being greatly in favour of this arrangement; and it is efficient, the cleansing of the coal being complete and the quality of the coke greatly improved.

In an example of coal washing on the above system in Wales, the length of trough over which the coal passes is only 240 ft.; the quantity of coal washed a day is 70 tons, from which about 8 per cent. of shale is removed. The cost in labour is equal to about three farthings a ton. In this case the water required for washing the coal does not require to be pumped; when this is not the case, the cost of pumping will considerably increase the cost of washing as here given.

Morrison's coal-washing machine consists of a cast-iron cistern 5 ft. long and 3 ft. 6 in. wide; to the back end a cylinder is fixed, in which works a piston, and this cylinder is connected at the bottom with the inside of the cistern. The front end of the cistern is made lower than the back, and it is fitted with a spout for conveying the washed slack to the waggons. Towards the top of the cistern is a false bottom composed of a perforated plate of copper, which is supported by a cast-iron grate; this false bottom is stopped short a few inches from the front end of the cistern, and over the opening thus left there is a plate extending from side to side of the vessel, which can be lifted by means of a handle; and this plate rests partly upon the false bottom. The water to the machine is supplied by a pipe and cock, and meets the coal to be washed as it descends from the spout.

The cistern being filled with water, and the material to be washed resting on the perforated false bottom, the reciprocating action of the piston in the cylinder forces the water through the perforations in the false bottom, causing the heavier particles to descend to the lower parts of the mass, while the pure coal, being lighter, remains at the top, and is carried by the stream of water over the front end of the cistern, down the spout, and into the waggons. When the dirt on the false bottom has accumulated to a certain thickness, it is allowed to fall into the bottom of the cistern, by raising the slide or plate above described. In the bottom of the cistern is fitted a second slide, which is opened occasionally and allows the dirt to drop out on to the ground, and from there it is filled into waggons and conveyed to the dirt-tip.

At Coxhoe, Lancashire, the cost of washing, with a Morrison's machine, was about three halfpence a ton. The percentage of loss depends on the purity or otherwise of the coals, and on their size. Duff, for example, of the Hetton seam, loses about 22 per cent., pea-small and duff about 18, and rough small 14 per cent.

Kingswood's washer is a double Morrison, arranged so that the dirt which falls to the bottom of the cistern, instead of being allowed to drop out upon the ground, is conveyed by elevators to a convenient point at the side of the machine, where a waggon can be placed to receive it.

The principle objection to these machines consists in the intermittent action of the piston; for while the downstroke forces the water up through the perforated plates, and causes the material that is to be washed to be held in suspension, so that the substance of the lighter specific gravity may be floated away, the upstroke creates a vacuum, and this brings the material down on the plate again. If a continued upward force were applied the machine would do double the amount of work. As a means of overcoming this objection, it has been proposed to shorten the stroke of the piston, or to run the same at a high speed, where the latter is available. If the water were supplied from a good head, through a series of small pipes, it would obviate the use of pistons, but more water would be required.

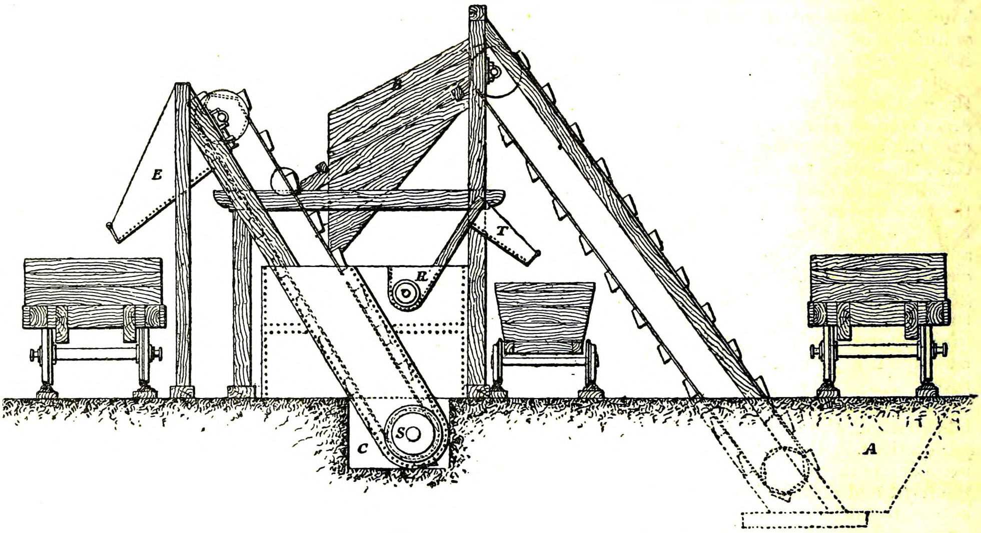
Green and Bell's coal-washing machine consists of a trough with a breakwater, and a door hinged at the bottom end of the trough over the refuse hole; and of a series of rakes which are worked by means of a crank, and a connecting-rod from any motive power. The dams and rakes are lifted by a handle and bell-cranks, the fulcra of the latter being supported from spars; and the bottom of the coal and refuse spouts are each provided with wire gauze to allow the water to pass into the outlet. The coals to be washed are put into the hopper, the door is opened to admit the coals into the trough, and at the same time water is let in by opening a cock, the water carrying the coals along the troughs. The coal, assisted by the action of the rakes, and being lighter than the contained impurities, is carried along the spout, over the dams, and finally over the end of the spout into the coal waggons. The foreign bodies are obstructed by the dams, and when these are silted up, the coal is shut off, and the rakes are thrown out of gear by means of a handle, which lifts the connecting-rod from off the lever of the rocking-shaft; and the dams, rakes, and refuse door being lifted simultaneously by the handle and bell-cranks, the water washes down the trough all the foreign matter, which falls through the refuse hole.

At Maesteg, near Bridgend, Shepperd's coal-washing machine is in operation; it is shown in side elevation, Fig. 839, and in section through the washing and settling chambers, Fig. 840.

The coal to be washed is delivered into a hopper A, from whence it is passed through a pair of rolls, and is then elevated to a screen B, by which the fine or dust coal is removed, and the remainder screened into three sizes, each size falling into a separate compartment, where it is washed by itself. The coal should be washed as soon as possible after being raised, as the coal dust when newly raised is nearly all pure coal. The shales come out in small cubes, or flakes, which will not pass through the fine wire that allows the dust to escape; but if the coal be kept long exposed to atmospheric influences, the shales will decompose, a good deal of them be reduced to powder, and some portions dissolved; whereas when fresh wrought, the short time during which the coal is subjected to the washing is not enough to dissolve these shales, and they are passed off with the pyrites and harder substances.

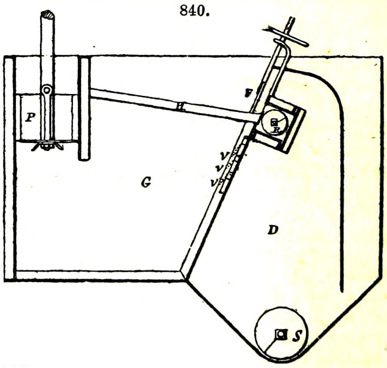
After washing, the coal falls into a trough C, where the water is drained off, and from whence the coal is discharged into a waggon or hopper. At the Llynvi Works the foul water flows into a settling pond, to allow the fine coal to subside; the water is then returned to the machine by a centrifugal pump, and is used over again. In other examples of this machine, settling ponds are dispensed with; a chamber D, Fig. 840, being added to the machine, and from this the water is returned for use through the valves *v* without pumping. The washed coal is passed from this chamber, by means of the endless screw S, into the trough C, and from thence it is raised by an elevator having perforated buckets, and deposited in the shoot E, from whence it passes into the coal waggons. These perforated buckets allow the water to drain from the coal and run back into the machine, and consequently there is no discharge of foul water; and a very small quantity is therefore required to keep the machine in action, only just enough to compensate for that which will not drain off from the coals. This arrangement removes one of the greatest objections to the use of coal-washing machines.

839.



After the screening and separating of the coal into various sizes, the sluice valves F, through which the rubbish passes, can be regulated, so that the opening in each valve may allow it to pass out and not the coal, as would be the case if small coal and large rubbish were in the same box. The shale is conveyed to the side of the machine by the screw R, and is discharged into the tram from the shoot T. The quantity of slag or shale removed varies considerably, depending upon the amount mixed with the small coal. Fourteen per cent. has been removed by this process, whilst the quantity of small coal which passed away with the shale was very small, and in examining these particles it was found that they generally had pieces of pyrites attached to them. The quantity of small coal carried off by the water, and collected in the settling ponds, varies from 5 to 8 per cent. of the total quantity passed through the machine.

840.



It has been found from experience that the smaller the coal the more dense the coke made from it, and thus it became desirable to attach crushing rollers, which in the case above mentioned are set to a ¾-in. gauge, through which all the coal passes. It may be desirable to crush some coals finer than others, but as the rollers determine the quantity of coal passed through the machine, and the regulation of the proper quantity of coal to each compartment, the ¾-in. gauge has been found to answer the purpose best in the above instance. A jigging screen has also been attached for the purpose of separating the coal suitable for each compartment; the classes into which the coals are separated are nuts, seconds, and small, and by this division the quantity of water required for the separation of the shale from each class of coal can be more easily regulated. The very fine dust is passed over without washing, as it was found that whilst working without screens the small dust had to go into the bashes with the rest of the coal, and was carried off by the water to the settling ponds, and these latter, therefore, became much more rapidly filled with small coal than when the screens were used and the dust passed over unwashed.

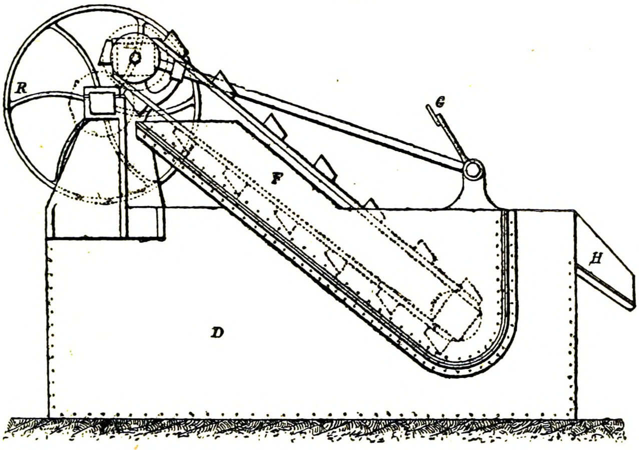
The cost of working this machine is a trifle over 2½*d.* a ton. This cost does not include the labour employed in putting the small coal to stock, or taking it from the stocked coal, if such has been found necessary.

As regards the continued using of the same water, it has been proved by experiments made by

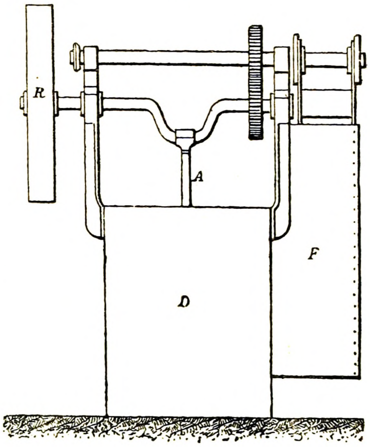
Howe, at the Clay Cross Collieries, that there is a great advantage in so doing; for the cost of washing was there reduced from 16·33*d.* a ton of clean coal delivered from the apparatus, when the water was allowed to run away, to 12·35*d.* a ton, when the water was used over again after having passed through the settling ponds.

Figs. 841 to 843 relate to Shepperd's machine for washing breeze and ashes, and is constructed on the same principles as the coal-washing machine. Fig. 841 is a side elevation, Fig. 842 an end elevation, and Fig. 843 a section through the machine.

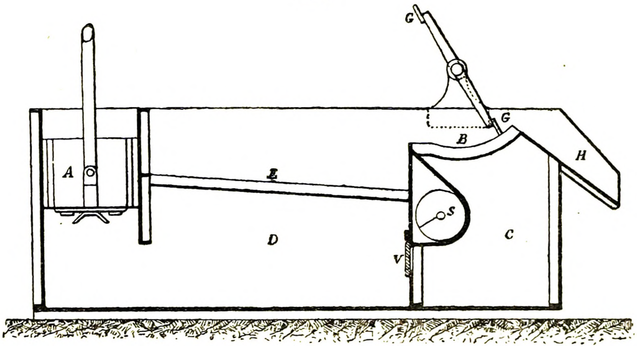
841.



842.



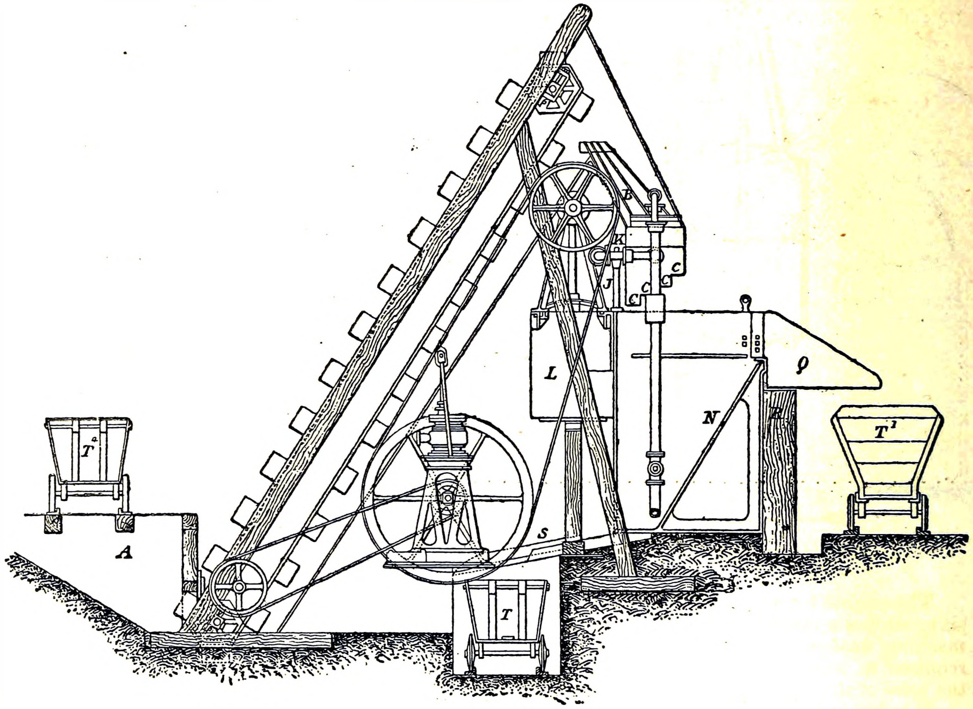
843.



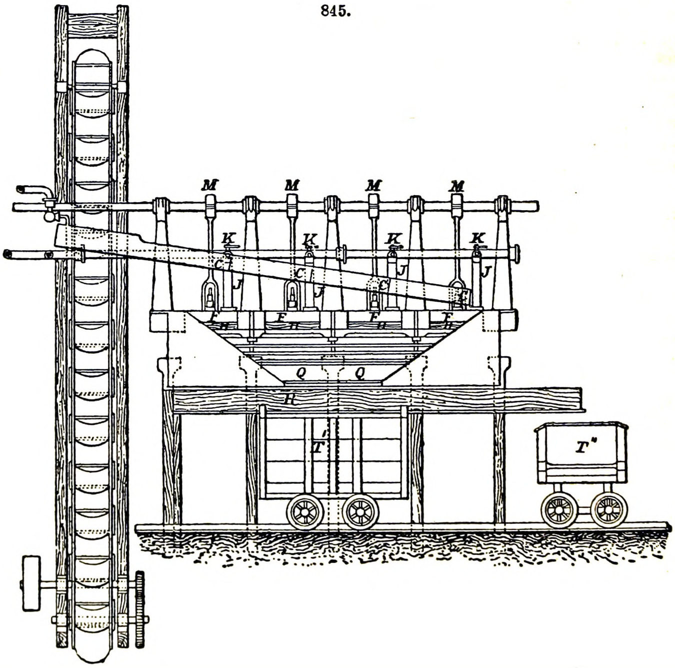
The clean breeze at each stroke of the piston A, is carried on to the perforated plate B, through which the water drains to the settling chamber C, and from thence it passes through the valve V, into the body of the machine D, to be again forced through the ashes; so that a continuous circulation of the same water takes place. The clinker, as it accumulates on the false bottom E, is removed through a sluice in the same manner as the shale in the coal-washing machine; it is then carried to the side of the machine by the action of the screw S, and from there it is raised by the elevator F, and discharged; the buckets of the elevator are perforated. The clean breeze deposited on B, at each stroke of the piston, is removed by the brushes G, and passes down the shoot H into the waggon. The brushes G are so arranged that the breeze deposited on the plate by one stroke of the plunger, is cleared away by a brush before another lot is forced forward by a succeeding stroke; the perforated plate is thus kept always open and so allows the water to drain quickly away. The quantity of water required to work this machine is very small; and the power required, with screen and elevator, is only about 3 to 4 horse-power.

Figs. 844, 845, and 846 are of Berard's machine. Fig. 844 is a side elevation, Fig. 845 a front elevation, and Fig. 846 section. The coal to be washed is discharged into the hopper A, and from there it is raised by an elevator, making one complete revolution for every seventy-four strokes of the engine, and from which it is worked by means of a strap and wheel gear. By this elevator the coal is delivered on to the inclined plane B, into the four troughs C; each of these troughs is 6 in. wide by 6 in. deep, and has at its end an opening 10 in. long by 4½ in. wide, which is situate immediately over the centre of each of the washing compartments D. A stream of water regulated by a ¾-in. tap washes the coal along each trough until it drops through the openings into the compartments D, each of which is 5 ft. 3 in. long, 3 ft. 3½ in. wide, by 1 ft. 6 in. deep; the bottom of D is formed of a copper plate $\frac{1}{16}$ in. thick, which is perforated with holes $\frac{1}{16}$ in. in diameter and $\frac{1}{8}$ in. apart from centre to centre; and this plate is supported by the cast-iron frame E, to which it is fastened by forty-eight ⅝-in. bolts; the plate G is to prevent the coal being washed too readily over the ledge H. A pipe J, of 1¾ in. diameter, conveys water to the under side of the perforated plate, the quantity being regulated by the tap K. A piston P, 3 ft. in diameter, working loosely in the cylinder L, and having a stroke of $12\frac{1}{2}$ in., communicates through a passage 19 in. high by 22 in. wide, with the under side of the perforated plate; this piston makes 120 strokes a minute, and receives its motion from an eccentric on the shaft M. The washed coal is conveyed by the shoot Q into the tram T'';

844.



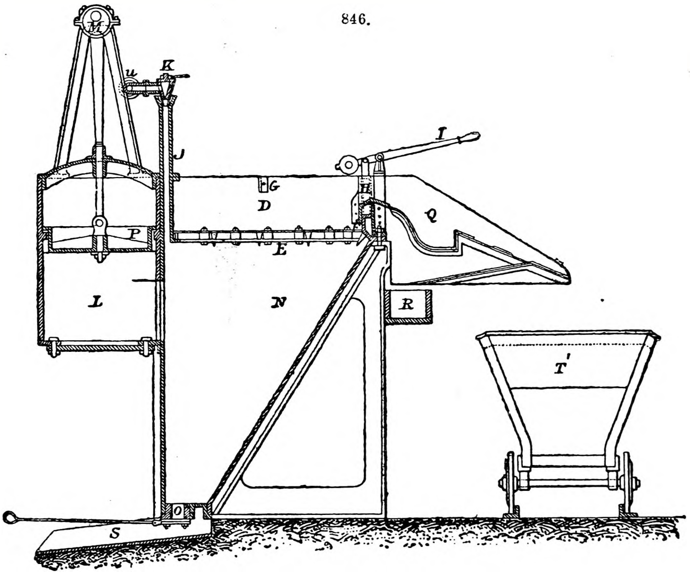
845.



this shoot is provided with a zinc plate $\frac{1}{8}$ in. thick, and perforated with holes $\frac{1}{8}$ in. in diameter, which allows a portion of the water and fine coal to drain along the trough R.

At the front of each compartment D, there is a valve F, 38 in. long and 3 in. thick for regulating the egress of the impurities; this valve is raised or lowered by means of the lever I. The shale after passing through the opening at F slides down the inclined side of the chamber N on to the valves O, which are from time to time opened to allow of its egress, it then passes over the screen S and is washed away to the rubbish heap; in its passage over S, any small coal which may have passed through the perforated copper plate, or been allowed to escape by the slide valve F, is received in the tram T, and is used for calcining ore.

846.



The engine for working this machine has a cylinder 12 in. in diameter, 16 in. stroke, and makes sixty strokes a minute, with a steam pressure upon the piston of 33 lb. a sq. in. At this speed the machine washes 15 tons of coal, and requires 18,800 gals. of water an hour; 4400 gals. being required to wash the coals along the four troughs, and 14,400 gals. under the perforated plates; the level of the water in the reservoir being 27 ft. above the level of the pipe U.

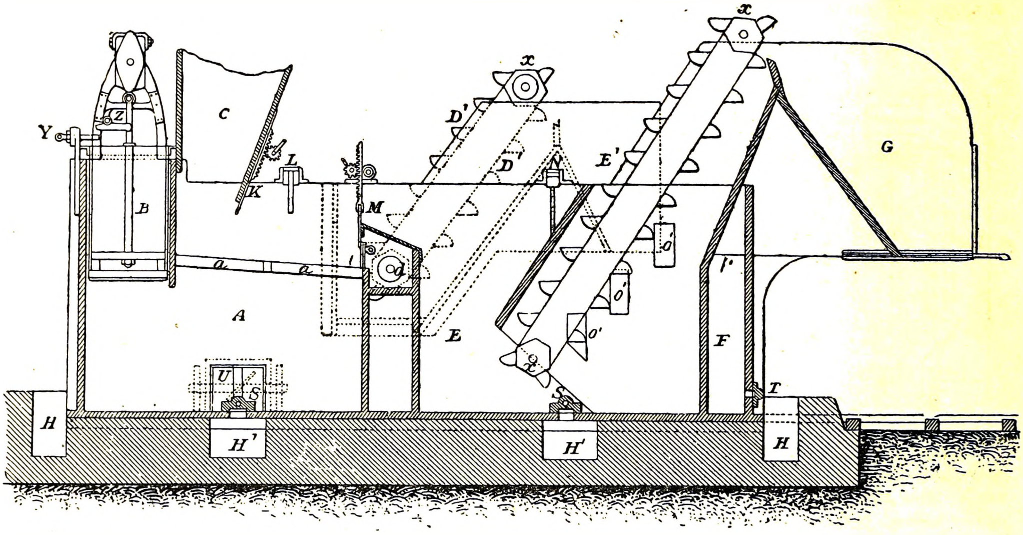
D being partially filled with unwashed coal, the water is turned on under the perforated plates, water also flowing along C and into D with the incoming coal; as the pistons P descend they force the water through the perforations in the copper plates, and so lift the whole mass of coal in D, the impurities descend and rest upon the plates; and this action being continued the coal fills up D and is washed over the ledges H, slides down the shoot Q into the tram T′, and along the trough R into the tram T″. These trams soon fill with coal and water, and as the coal continues to fall into them the water flows away over the top of the tram; this water is conveyed by pipes to a catch pond, 100 ft. long, 6 ft. wide, and 2 ft. deep, where a portion of the finer particles of coal carried away by the water is deposited; after overflowing this catch pond the water is caught in a second of the same dimensions, and from this it is allowed to flow away. When it is found that the shale has collected to a depth of about 6 in. on the bottom of D, the slide valve F is lifted by the attendant, and it passes into the chamber N. The loss of coal in washing is from about 10 to 12 per cent. when weighed saturated with water; and there is a further loss of 8 per cent. when weighed quite dry.

The cost of working is about 4*d.* a ton. At the Park Colliery, Tondu, 1869, they had washed 1924 tons of coal with Berard's machinery, at a cost of about 3·84*d.* a ton. The machine, when in full work, washed 200 tons of coal a day of ten hours; 6241 gals. of water an hour passed through the catch ponds from the machine, and each gallon of water contained on leaving the catch pools 103·3 grains of impure coal in suspension = 92·2 lb.; the coal suspended in the water was separated for examination and estimated by filtration, a portion was burned in the muffle and yielded 25·91 per cent. of ash. The 92·2 lb. of coal carried away by the water an hour, multiplied by 10, the number of hours which the machine worked to wash 200 tons = 922 lb., and this divided by 200, the number of tons of coal washed = 4·61 lb. of coal carried away to the ton of washed coal, or 0·21 per cent. The fine coal left in the catch pond, was of a very impure quality, and contained as much as 10·13 per cent. of ash. The block or large coal from which this small was separated by screening contains 2·27 per cent. of ash, but in working the coal there becomes mixed with the small, from a variety of causes, a large quantity of rubbish, which raises the ash in the small coal to about 11 per cent. The coal lost with the rubbish that is taken out of the bottom of the machine at the valves O, Fig. 846, is but trifling.

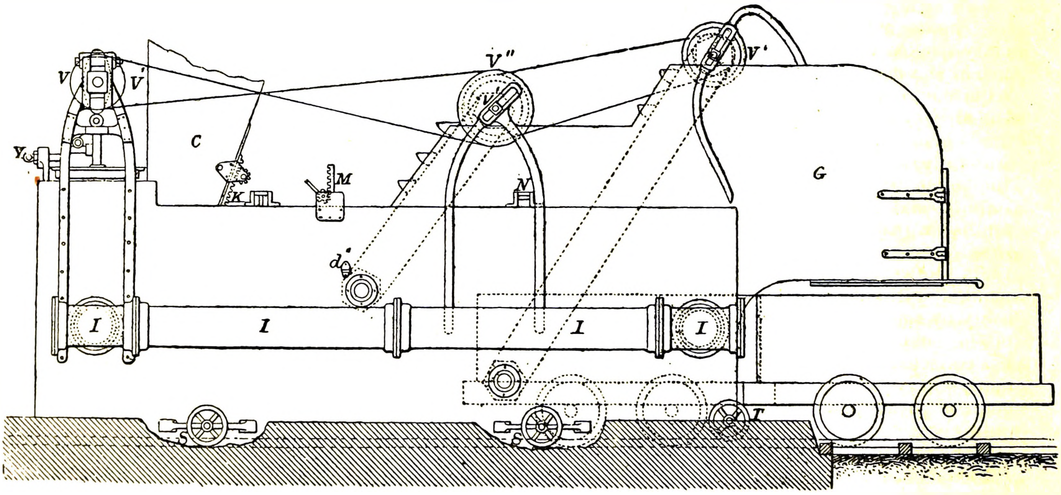
Rivière's machine is shown in Figs. 847 to 849; Fig. 847 is a longitudinal section, Fig. 848 a side elevation, and Fig. 849 a plan. It is an adaptation and improvement of several existing coal-washers. The body of the apparatus and the piston may be constructed either of wood or of sheet iron; in the figures the apparatus is shown as it should be when made of wood, and the piston of sheet iron.

The water is introduced below the screen or into the compartment of the piston, and the supply regulated; the coal enters the hopper C, and the coal dust to be washed between the grating I and the slide K. By introducing the coal to be washed into C, with regularity and in small quantities at a time, the gate K may be entirely raised, and the washing proceed the whole length of the screen; if, on the contrary, the coal is supplied irregularly, or in large quantities at a time, the gate should be more or less lowered, according to the physical condition of the coal. The grating L breaks up the agglomerations of small coal; it is comb-shaped, and is formed of bars, which do not penetrate the coals too much. The slide M, which is moved by means of racks in the same manner as K, increases or diminishes at will the thickness of the layer of coal submitted to washing on the screen; this slide forms its movable overfall, and extends the whole width of the tank. In the compartment D, an endless screen *d* conveys the shale into the compartment D'', from whence it is carried away by an elevator D'. The shale passes into the compartment D by the openings *d'*, which are opened or shut by means of a slide working in grooves and moved from the outside by means of a handle *d''*, which forms the extremity of a guide rod, sliding in a stuffing-box. The grating N, in the tank E, serves to retain the floating refuse which would pass through the grating L, which corresponds with it, with the exception that the bars of the latter are wider apart. The partition O, which, with the exception of the sloping of the sides in the upper portion, extends over the whole width of the tank, facilitates in front the depositing of the small coal with the washed coal, and prevents the elevator buckets ever becoming overcharged with washed coal, which may at times be produced in excess; its lowest position must be determined by experience. This partition confines the agitation produced by the buckets; the openings *o'* permitting the small coal to pass into the compartment, but not to pass out, because there is no side current of water, or rather, because there is one which passes from without into the compartment O, to replace the water carried away with the washed coal by the buckets. The partition *e* extends over the whole breadth of the washing machine; it is carried a little higher in R and R' than in the compartment O, where it is limited and continued by the separate bottom of the elevator cage. Between *e*

847.

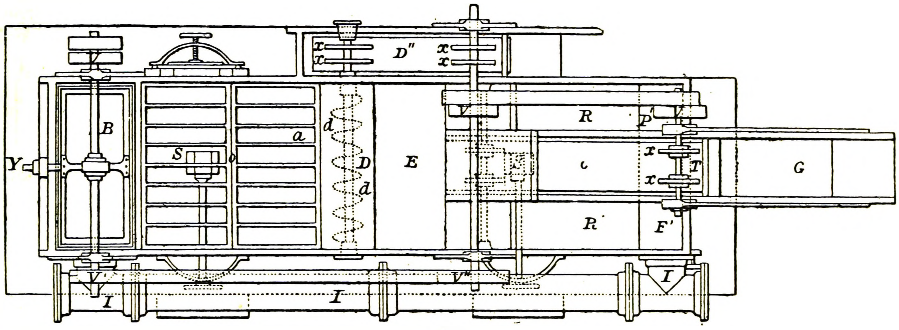


848.



and the trough there are two compartments, F and F′. F receives the current of water in its upper part on two sides; that which passes through R, Fig. 849, is received by the opening P′, and through R′, by an opening, which is above the bottom *p*, Fig. 847, and laterally under the bottom of the cage. F′ is separated from F by the continuation of the partition which limits the compartment R′, and bears a clack, which closes the pipe I. In the upper portion this compartment is shut by a movable bottom, which serves to fix and examine the valve to which, if needful, a weight is added to facilitate its shutting; and for the same purpose the clack seating is fixed at a slight angle from the vertical.

849.



When the piston B, Fig. 847, is lifted, the suction produced opens the clack valve, and a current is established by the return water pipe I, from the tank E, at the lower part of the tank A, under the piston B and the screen *a*. When the piston descends the pressure closes the valve; the repelled water traverses the screen, lifts the coal, classes it, and carries with it the upper layer of washed coal into the tank E, where it is deposited, and from whence it is lifted by the chain buckets into the hopper G, under which the trucks are placed to be filled; this hopper is shut in front by a door hung on hinges, which is so arranged as to be opened at will, and can be shut by pulling a long handle when there is no truck below to receive the coal, which is thus thrown into the hopper for a time, and stoppages avoided. The position of the truck which receives the shale at the side of the washing machine is shown in outline in Fig. 848.

As the production of the machine may vary, according to the nature of the coal which is being washed, the number of piston strokes a minute, the position of the gates K and M, and from other causes, pulleys of different diameters V, V″ have been provided, in order to increase or diminish the relative speed of the chain buckets E′, and the same might be done for the pulleys *v*′, *v*″. The pulley V, which is attached to a loose pulley, receives the power for driving the washing machine, and the shaft which carries this pulley and the cam J may at times be conveniently made the driving shaft; in which case the pulley V would be useless, and the loose pulley would be by the side of the pulley V″ or of the pulley V′. When it is desired to stop the work of the piston, without stopping the movement of the cam, the bolt *y* is drawn when the piston is at the bottom of its stroke, and the cock *z* is lowered. A speed of thirty to forty strokes a minute is a good medium speed for this machine.

The gate S′ is provided for freeing the chain for lifting the coal when it has become accidentally entangled; it serves also to empty the tank E when necessary, which, however, is very seldom. The gate S may serve to empty the silt from the tank A, but most generally it is preferred to let the silt accumulate in the tank, and then to empty the water through a hole, made below the piston in the back of the washing machine, which is closed by a wooden plug. The water having run out, the door U is opened, and the silt removed and heaped aside, to be passed during working behind the special grating L. The gate T serves to empty the compartment F. The emptying gates are controlled by means of a rod with screw and flyer. At the end of the compartment F′ another small gate or opening is placed, which is shut by a plug, and through which the water may be emptied from the tank A by means of the return water pipe. When the washing machine is built on masonry, it is well to have a canal H round it. In order to clean the return pipe I, one of the head joints is opened; the escaping water cleans it sufficiently, especially if the introduction of water into the washing machine is continued for a few minutes, and if the silt is stirred. It will answer the purpose simply to take out the plug of the compartment F′. In any case, in order that it may be easy to open and close the head joints, they are kept shut by eye-bolts and keys; but as this pipe does not get choked, it seldom requires cleaning.

This machine is stated to work with great economy, and to produce good results.

In Marsault's coal washer the body of the machine consists of a large oak tank, 6 ft. long, 10 ft. wide, and 24 ft. deep; open at the top and with sliding doors in the bottom, by means of which the slimes can be discharged without stopping the action of the machine. Above the tank an inverted hydraulic cylinder is fixed, to the piston rod of which is attached an iron cage, 10 ft. in height; the ends of this cage are left entirely open, the bottom being formed of an ordinary coal-washing sieve; on the closed sheet-iron sides there are fixed, one above another, a series of horizontal ledges, on which slide three rectangular wooden frames, fitting loosely within the cage, and made like drawers without bottoms, the depth of each frame being determined by the nature of the coal to be washed. This cage slides between guides, which are fixed from the top to the bottom of the washing tank, between the slides of which and the cage there is a clearance space of less than one quarter of an inch.

The tank being filled with water, and the cage fixed up in the top of the tank by means of bolts at the sides, a charge of from 3 to 5 tons is let fall into the cage from a shoot placed over the machine, at a height above the top of the tank determined so as to ensure the whole of the stuff becoming at once thoroughly soaked by falling into the water in the tank. In order to equalize the distribution of the charge over the whole of its area, the loaded cage is first subjected to two or three jigs of considerable height, after which it is allowed to fall to the bottom of the tank by a regular succession of short drops, adjusted beforehand to suit the size of the stuff treated, and this height is capable of being varied as circumstances may require, from ¾ in. to 8 in., by regulating the escape of the water from the hydraulic cylinder from which the cage is suspended. At each drop of the cage the water passes through the sieve, in the upward direction, at a speed due to the restricted area of passage and the relative weight of the immersed cage with its load; and the mass of stuff in the cage is thereby lifted off the sieve, or rather the sieve drops away from beneath it, while the charge remains momentarily at rest; then all the separate particles of the charge fall severally through the still water with their own individual limiting velocities, modified only by their mutual interference as in all washers. With a charge of from 4 ft. to 4 ft. 3 in. in thickness in the cage, a total broken fall of 10 ft. to 13 ft. through the water is generally sufficient; if, however, the tank should not be deep enough, or the sorting not perfect, the fall can be repeated, with the same charge, as many times as may be necessary. On the cage reaching the bottom of the tank, a few seconds' pause is made to allow the largest of the minute light particles, which have not fallen so fast as the rest, to become deposited upon the charge. The cage is then drawn up out of the water, and fixed in position by the side bolts; the three sliding frames successively pushed out at the front by the action of a horizontal hydraulic cylinder placed behind them; and by these means the washed coal, the stuff to be rewashed, and the shale, are each discharged into a separate hopper. On a level with the upper part of the washing tank is an overflow tank, equal in area, and its depth 2 ft. 6 in.; the object of this tank is to diminish the variation in the water level in the washing tank, consequent upon the alternate filling and emptying of the cage; a return pipe leads from the bottom of the overflow tank into the lower part of the washing tank, and this pipe is fitted with a floating check-valve, which opens downwards, so as to prevent the water from being driven upwards through it during the descent of the cage. The same water is used over and over again, the only loss which has to be compensated for being the small quantity which is carried off with the washed stuff; and the whole of the water is drawn off and renewed, when found necessary, during the time that the apparatus is not at work.

From 120 to 150 tons of washed coal can, without difficulty, be turned out in a working day of ten hours, from a machine of the dimensions given, by one man; the power required to work the machine being about 1 horse-power.

COAL MINING.

The special characteristics which divide the winning and working of coal from other modes of mining, are caused by it having usually to be won from below strata whose mineral character often occasions great difficulty, and from the fact that coal is nearly always met with in layers, and has to be raised continuously in considerable quantities; whilst the common occurrence of explosive and poisonous gases requires peculiar ventilating arrangements.

The design and disposition of the surface works are arranged in accordance with the magnitude which it is intended the underground workings shall assume. In opening up a new colliery, the laying out of the pit bank and the erection of the surface buildings will be carried on simultaneously with the preliminary operations below ground, in order that the requirements of the workings may be met as soon as they are sufficiently developed to allow the output to be commenced.

The pit-head gear is erected in connection with the floors and staging by which the pit mouth is reached, and upon which the coal, as it is landed, is run out, weighed, and tipped. This staging is at such a height from the general level of the ground that an ordinary railway truck can be run underneath to receive the coal tipped from the tubs in which it is brought to surface. It is not often, however, that the coal is tipped directly into the trucks or waggons; usually it is shot out upon a system of screens, by means of which the various sizes are separated. In such a case, a waggon is placed under each screen, and these waggons are run out and assorted as they are filled. But before the tubs are tipped they have to be weighed. The operation of weighing is effected by running the tubs on to a weighing machine, which for convenience may be placed between the pit mouth and the points from which the tubs are tipped over the screens. After being weighed, the tubs are run out to the tipping points, where they are made to pass on to the tipping or teeming cradles, Fig. 850, which are wrought-iron cages mounted on trunnions; these hold the tubs while their contents are being tipped over upon the screens. It is easy to see that all of these arrangements admit of endless modifications. The pit-head gear usually stands out in the open air; the staging around the pit mouth is sometimes left exposed, and sometimes covered in by a light wooden roofing as a protection from the weather; but as the sides are left open the protection is only partial. Upon the Continent, and especially in France and in Belgium, the whole of the head-gear and the staging is enclosed, so that the men may work in comfort during bad weather. Fig. 851 is of a pit-head and accompanying staging, and is a common arrangement in many English collieries.

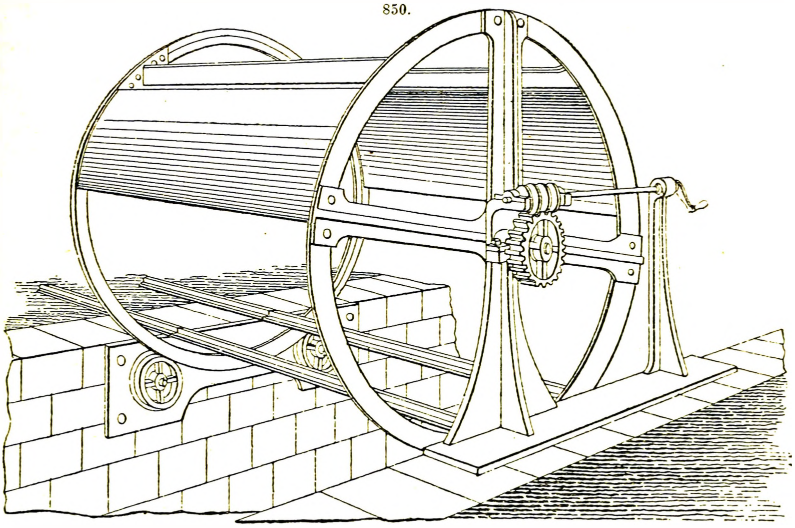
The engine house on the Continent is included under the same roof as the head-gear and the pit-mouth platform, the former of which is made to occupy a central tower or dome; but in England it forms a separate building, the position of which must be selected with reference to convenience, having regard to the operations to be carried on at the surface. Besides the winding engine house, there will be required an erection for the pumping engine, and several lesser buildings as workshops and offices.

In cases where coal washing is practised, machinery similar to that described at p. 360 of this

Supplement, with the necessary erections, will be required, and when a colliery is so situate that its produce may be conveyed away by water carriage, the surface works will include a wharf, and the means of discharging the coal into the vessels lying alongside.

Other structures that may have to be provided are coke ovens. Where the coal is of a quality that renders it suitable for metallurgical operations, a large proportion of it will be converted into coke for use in the blast furnace. But coking may be required in any locality, for steam and other purposes, and it affords a means of utilizing the small coal made in working. Some varieties of coal are of a very tender character, and it may become a commercial necessity to render it saleable by converting it into coke. In such a case, ovens will have to be erected, and these will require to be disposed in a convenient manner and in favourable positions relatively to the pit mouth, and the points from which the produce is conveyed away.

850.



Besides the erections described, the surface works include a system of tramways for conveying the produce from one point to another. In some cases, this system will be an extensive one, especially when coking is carried on largely. The surface tramways are laid with heavier rails than the underground; but otherwise they are the same in character. They should be laid out, or rather the points which they serve should be selected, so as to utilize as much as possible the force of gravity. Frequently, at large collieries, small hauling engines are erected at surface to work these tramways.

The shaft or pit of a coal mine constitutes the means of communication between the underground workings and the surface.

Shafts are classed and described according to the uses to which they are put. Thus we have an engine shaft, up which the water is pumped, and over which the pumping engine is situate; a winding or drawing shaft, up which the mineral is raised, and in connection with which the winding engine is erected; an air shaft, which is sunk to a seam for the purpose of providing ventilation; a downcast shaft, down which the fresh air passes to the underground workings; and an upcast shaft, up which the fouled and heated air passes from the workings to the surface. These designations frequently refer to only one of several uses of the shaft, for winding may be, and usually is, carried on through both the downcast and upcast shafts, and the pumping may be performed through either.

It was formerly the practice, in small mines, to sink but one shaft to the seam, on account of the cost, and this shaft had then to serve for all purposes, and was divided into several compartments, one for the pumps, and two others for the winding, while the air was conveyed down one of these and up another, or the two others. This arrangement was, however, dangerous; and in the United Kingdom it is now illegal to work a coal mine with less than two shafts. In all cases the number of the shafts should be reduced to the lowest practicable limit, and their dimensions large enough to supply sufficient air to the workings, and allow the passage of the cages; and the winding should be carried on at a high speed. The actual number of shafts requisite can be determined only by the conditions of the case.

The form of the shaft varies considerably. The determining conditions are the strength of the rock passed through and the material available for supporting the sides. When the sinking is through plastic clay or running sand, and whenever the rock is of a weak and unstable character, the circular form is the most suitable. Where wood is abundant, rectangular and polygonal shafts are commonly employed. Rectangular shafts are never made square, and their length varies from about once and a half to three times the breadth.

Shafts also vary greatly in their dimensions, but can hardly be too large. Circular shafts should never be less than 9 ft. in diameter, and they may be as much as 16 ft. In some instances elliptical shafts have been sunk 18 ft. and 20 ft. The upcast should possess a larger diameter than the downcast. When the section is rectangular, the dimensions are very various, ranging from 4 and 6 ft. in breadth, by from 9 to 16 ft. in length, to 10 ft. in breadth by 26 ft. in length.

The position of the shaft is determined by many conditions, chief amongst which are the dip of the strata, the degree of their inclination, the quantity of water likely to be met with, and the character of the seam as a source of explosive gas; the proposed method of working the seam, and the general plan of the workings.

The circumstances existing at surface will modify the decision arrived at from the foregoing considerations, and not unfrequently alone determine the choice of the position; that is, the position chosen in accordance with the surface conditions may be unfavourable to the conditions prevailing underground. The coal will have to be conveyed to the nearest highway, canal, or railway; and the situation of the coal-field relatively to these, the surface configuration of the locality, and the existence of natural and artificial obstacles, will influence the position of the shaft, between which and these means of communication a constant connection must be kept up. Generally, this will be made by tramway, and the foregoing circumstances will, therefore, have to be considered relatively to the requirements of such means of transport. Sometimes no railway may exist, but it may be intended to construct a branch to the colliery from a line a few miles distant. Advantage should always be taken of gravitation to run the loaded trucks away from the shaft in order to save expenditure. But to do this, a position must be chosen for the shaft sufficiently elevated above the railway or the canal, and to make this position accord with the other conditions.

In some localities, it may happen that quicksands or unstable drift will have to be passed through, and it then becomes a question of passing through these beds in the most favourable part. Numerous instances might be cited in which altogether unfavourable positions have been selected for the shafts, solely for the purpose of escaping the difficulties that would otherwise be encountered in traversing such beds.

It has been already remarked that the minimum number of shafts to every colliery is two. These must not be separated by less than 10 ft. of natural strata; but beyond this limitation they may be placed at any distance apart, and in any position relatively to each other that best fulfils the foregoing conditions, and is suitable to the system according to which the workings are to be aid out. Sometimes it is found convenient to separate the shafts by long distances; but generally they are placed only a few yards apart. By bringing the shafts near together, the points of delivery, and the machinery required at those points, are concentrated at one place at surface.

When the shaft has been completed and sunk to the coal, to proceed at once to the working of the mineral would be to endanger the safety of the shaft, and to create serious obstacles to the subsequent working of the seam and the efficient ventilation of the working places. The extent to which the mine should be opened out will be determined by local, commercial, and other considerations. The more systematically and completely this opening up of the ground is performed, the more economically and safely may the extraction of the coal be effected. It is a false economy to curtail the time and expense requisite to the opening out of a colliery, since the consequent difficulties, which can never be removed subsequently, or even modified in an important degree, more than compensate the first expenditure of money, or the inconsiderable gain of time.

As the opening out of a mine is not immediately remunerative, it is described as dead work, or frequently, on account of the narrow width of the working face, as compared with the ordinary working places, as narrow work. The excavations which constitute the dead or narrow work consist of drifts, headings or roadways, called rolley-ways, way-gates, gate-roads, water-gates, and levels, driven out from the mass of coal left to support the sides of the shaft, and called on that account shaft pillars. These levels are the principal roadways, airways, and waterways of the mine; through them all the produce of the mine will have to be conveyed, and the whole of the air which is to ventilate the workings, as well as the water flowing therefrom, will have to pass. The mode of laying out these pioneer excavations will be in the main the same, whatever the system of working adopted may be. But modification may be required to conform to the exigencies of the case, due to the angle of dip, the existence of faults, or any other of the numerous circumstances that may accompany the occurrence of a seam. In the example which we shall assume for purposes of illustration, the seam will be supposed to dip at a small angle, and to be free from disturbing circumstances, in order to form a typical case, that shall involve a system in its entirety.

A large mass of coal must be left unwrought around the shaft, as a support; this mass will be cut through only by the narrow excavations that constitute the roadways to the shaft. These drifts divide the mass into detached blocks, which are called the shaft pillars. The slightest movement in that portion of the beds through which the shaft passes must necessarily be destructive to the latter; and hence it is essential to provide sufficient means for preventing such a movement from taking place.

The dimensions of the shaft pillars are determined by the depth of the seam from surface; the angle of inclination of the beds; the strength of the coal; and the nature of the thill or floor. According to André, in no case can safety be obtained with pillars less than 35 yds. square; these may, therefore, be considered as the minimum dimensions in the shallowest mines, when the other conditions are favourable, say up to a depth of 150 yds. Beyond this depth the dimensions may be increased by 5 yds. for every 25 yds. of increase; that is, the pillars of a shaft 175 yds. deep will be 40 yds. square; those of a shaft 200 yds. deep, 45 yds., and so on. These dimensions are given as sufficient, on the assumption that the other conditions are favourable. But it is evident that those conditions may be such as to require an augmentation of the dimensions, as determined according to the depth alone. Thus, if the strata are highly inclined, the tendency of the pillars to yield is greater than when the strata are flat. The difficulty of preserving the shaft through steep measures is, in Belgium, often found to be a serious one. The strength of the coal will also materially affect the resistance of the pillars to compression. The difference in the strength of coal is very considerable, and this difference must be taken into account in determining the dimensions of the pillars. But perhaps the most important of these determining conditions is the nature of the thill or floor of the coal seam. When this floor consists of soft underclay, the pressure of the pillar upon it tends to force it to rise in the roadways between the pillars. This tendency of the floor to rise between the pillars, or creep, is often very observable in the workings. The displacement of the floor in this way causes the pillars to sink, and the downward movement

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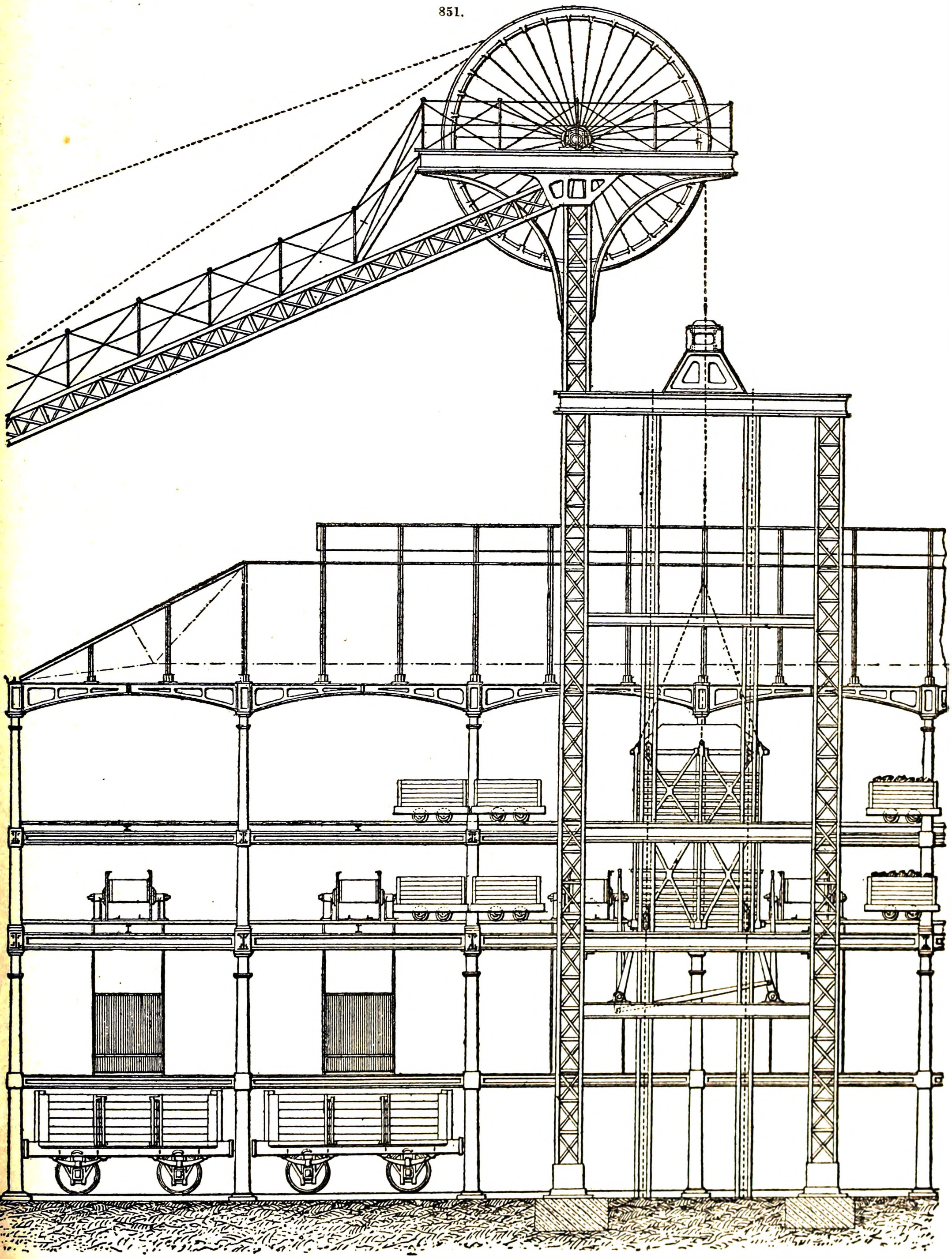

of the superincumbent beds is accelerated by the crushing effects which take place in the pillars, by reason of the unequal strain thrown upon them. The only way of counteracting this tendency is by increasing the dimensions of the pillars, so as to distribute the pressure over a wider area.

The amount of increase demanded by each of these conditions cannot be stated in a general manner. It is a question that will have to be determined for each individual case, in accordance with the circumstances by which it is surrounded, and the degree in which the conditions are modified. The proper method of procedure, in dealing with this question, is to determine the dimensions required by the depth alone, and then to augment these, if necessary, for each of the other conditions, in a proportion adequate to its requirements. The experience of the district will in this matter be of great avail.

When the dimensions of the shaft pillar have been determined, the levels may be set out, the designing and driving of which constitute the work of opening out the mine. The direction of these levels is determined by that of the dip of the strata, and the relative positions of the downcast and upcast shafts will be dependent upon the same conditions. As the levels are to be driven in the seam of coal, the horizontality of their floor, whence their designation of level is derived, can be obtained only by driving them in the direction of the *strike* of the beds, which is at right angles to their dip. In this direction, therefore, which is known among miners as the water-level direction, is that of the levels to be driven out from the shaft. These so-called levels are, however, not perfectly horizontal, but their deviation from the horizontal is made as little as the conditions will admit. A consideration of the conditions which determine the position and the direction of the levels will show that these must greatly influence the choice of the position of the shafts. The relation of the levels to the shafts and to the coal to be wrought, in position and in direction, will be understood by a reference to the plan shown at p. 975 of this Dictionary. This plan represents typically a method of laying out the workings frequently followed in England.

The direction of the dip of the seam is shown in the plan by the arrow upon the coal to be wrought. The downcast shaft is at P, and directly to the rise of the downcast is the upcast shaft. When these shafts have been carried down to the requisite depth, they are connected by a drift driven through the coal. This provides for the ventilation by enabling each shaft to serve the purpose for which it was ultimately intended; for the current of air, instead of passing down and up each shaft on opposite sides of the temporary brattice in the shaft, will now descend through the downcast, and a scend through the upcast. It now remains to set off the levels perpendicularly to the direction of the dip of the seam. These are driven out from the shafts in opposite directions, and as they will be in all respects identical on each side of the shafts, it will be sufficient to describe those on one side only. Before describing these levels, however, it should be observed that in extensive collieries a third level is usually added, mainly to ensure a more efficient ventilation; and also that the shafts may be situate farther apart than in the example.

In driving the levels out from the shafts, a walling is necessary to sustain the sides and the roof of the level, timbering being insufficient generally. Whenever timbering is used to support the roof in such situations, it will be well to wall the sides. But an arching of brick is far preferable; and if the floor is of a weak character, the walling should rest upon an invert.

The lower level is the drain, water-level or water-gate, one of its uses being to convey the water, which gravitates towards it from the workings situate above, to the pumping shaft. The upper level is the main road, rolley-way, or way-gate, through which the mineral will be conveyed to the shaft. These are the main outlets to the mine, and constitute the air-channels through which the workings will be ventilated. The facilities which these roads afford for the easy and rapid transport of the coal from the working faces to the shaft, will very materially influence the quantity of the output and the cost of delivery at surface, or bank, as the surface around the mouth of the shaft is technically called. And the consequences of an accident resulting in the blocking up of these roads are of a too serious character to leave any precaution unnecessary.

When timbered, the sides of the section of a level are generally vertical, and the top or roof horizontal, the section in such a case being rectangular. The sides may, however, incline towards each other, thus giving a greater width at the floor than at the roof. When walled, the sides are vertical, and the roof is arched.

The dimensions will be determined by the thickness of the seam through which the levels are driven, the strength of the roof, and the requirements of the means of transport. If the seam is of moderate thickness, say from 6 to 8 ft., the level will be driven between the roof and the floor; that is, the whole of the seam will be removed, and the height of the level will be equal to the thickness of the seam. When the thickness exceeds 8 ft., the level is driven from the floor to a height of 7 ft., or 7 ft. 6 in., and the remainder is left to form the roof. When, on the contrary, the seam is too thin to afford a convenient height for a horse-road, either a portion of the roof must be stripped down, or a portion of the floor removed to give the necessary height; and as such labour is altogether unproductive, the minimum height demanded by convenience will not be exceeded. Under some conditions this may be as little as 5 ft. The width of the excavation will be determined according to the strength of the roof and the requirements of the means of transport. If the roof is of a very weak character, it may be necessary, to ensure safety, to limit the width to 5 ft. If, on the contrary, the roof is very strong, this width may be increased to 10 ft. Thus the limits of height and width of a level may be stated as 5 ft. and 8 ft., and 5 ft. and 10 ft. respectively. The width necessary to convenience of transport will be determined by the extent of the workings, and the degree of activity to be developed in them. In most cases, the rolley-ways will have to be laid out to a width sufficient for a double line of tram rails, so that a train of empty tubs may be returning to the workings while a train of loaded tubs is running out towards the shaft. In general, the best width is from 7 ft. to 8 ft., when the strength of the roof is sufficient. For economical reasons, the sectional area of a level is frequently reduced to its lowest practicable limits; but to assume that the cost of driving a level diminishes as its sectional area is an error. When the miner is compelled to work in a space insufficient to allow freedom in his movements, there is a loss of useful effect, which, by prolonging the labour, increases the cost of the work. Also the labour of driving a heading of small sectional area is relatively greater than that required by a heading of larger dimensions, since the amount of side cutting is proportionally greater in the smaller section. Besides this, the coal extracted from the smaller face is more broken, and consequently less valuable, than that hewn from the larger face. The only advantage offered by the smaller section lies in the diminished labour of conveying away the dislodged mineral.

The levels have a slight inclination towards the shaft to allow the flow of the water towards the bottom of the shafts from which it is to be raised, and to facilitate the bringing out of the trains of loaded tubs. By adapting the fall of the road to the load to be conveyed over it, a large saving of labour may be effected, an advantage particularly noticeable when horse power is employed as the means of traction. Experiments have shown that an incline of 1 in 130, or a little more than ¼ in. in the yard, gives the maximum of advantageous effect to horse power, in drawing the loaded tubs down and the empty ones back, and therefore, where practicable, this inclination should be adopted. But in very long levels, such as are driven when it is desired to gain the greatest possible area from one winning, this degree of inclination would be too great, as the extreme end would be too elevated. In these cases the inclination given to the level is usually 1 in 200, or a little less than $\frac{3}{16}$ in. to a yard. A level should preserve in every portion of its length a rectilineal character; that is, it must be driven from one end to the other in a perfectly straight line, and if the circumstances do not allow of this, it should be driven on a curve with a large radius.

There are two systems of laying out the workings of a colliery, differing in their general features, but capable of such modification as to be greatly assimilated in certain circumstances. In one system, a set of parallel excavations is driven through the coal at intervals, so as to leave a rib of coal between them to afford a support to the roof. These excavations are made as wide as the strength of the rock will admit, a common width being from 4 to 5 yds. At right angles to these another set of excavations is driven, also parallel with one another. The width of the latter is usually about half that of the former, and their interval apart is much greater. The effect of these two sets of excavations thus crossing each other perpendicularly is to leave in the seam rectangular blocks of coal, for the second set is driven through the ribs left between the excavations constituting the first set. The use of these pillars is to hold up the roof; formerly they were left, and as the coal composing them was permanently lost, it was sought to reduce their dimensions to the lowest possible limit. Under favourable circumstances, however, fully one-third of the seam was necessarily lost in these pillars, and very frequently the proportion was as great as two-thirds. In the present day, these pillars are subsequently removed and the roof let down, so that generally the whole of the coal, with the exception of a small portion of the pillar which is crushed by the descending roof, is extracted. When the workings are laid out with a view of finally removing the pillars, the latter are left of very large dimensions, for the purpose of affording a thoroughly efficient support to the roof during the first part of the working, that is, during the driving of the excavations. This system is known in England as that of pillar and stall, or post and stall, and in Scotland as stoop and room. The stalls are the excavations which are driven through the coal, the first set of which is known distinctively as boards, sometimes written bords; and the second as headways.

In the second system of working, the whole of the coal is removed at once, in a long and continuous face, and the roof is allowed to fall behind the workmen. To prevent the roof from falling upon the miners at work, a double row of props is set at a distance of about 6 ft. from the face, and moved forward as the face advances. This system is obviously far more simple than the preceding, and it may be remarked here that it is gradually supplanting the post-and-stall system, wherever the conditions are not altogether unfavourable to its adoption. This system is known as the long wall. The relative merits of the two systems of working coal have been a subject of dispute ever since the long wall was first introduced. Undoubtedly each possesses peculiar advantages, and it will be our endeavour briefly to point these out, and to show how each is affected by various conditions and circumstances.

The ultimate object in every working for coal, whatever the circumstances may be under which it is undertaken, or the method by which it is carried out, is to obtain the greatest possible quantity of coal, in the best possible condition, at the least possible cost. In estimating, therefore, the merits of any system or mode of working, its effects must be considered relatively to this object. The condition of cost must be understood to involve the question of safety of life to those employed in prosecuting the workings. The produce of a coal seam will be obtained in the best possible condition, when it is all extracted and conveyed to bank in blocks of considerable size, or is obtained as round coal. If the two systems be considered from this point of view, it will be found that the long wall will give the greatest quantity of coal. When the workings are carried out according to this system, the whole of the seam may be extracted; whereas, on the post-and-stall system, a portion of the pillars, greater or less according to the circumstances of the case, is necessarily lost. Thus the long wall gives the greatest possible quantity of coal. Also, the coal got by this system is less broken than that obtained by post and stall, as the narrow workings of the latter system occasion the making of a large quantity of small coal. This quantity is increased, sometimes very largely, by the crushing of the pillars as they are worked away. This breaking up of the coal is inherent in the nature of the system, and therefore, however skilfully it may be carried out, it must remain inferior to the other system in this respect. Thus the long wall gives the greatest possible quantity of coal in the best possible condition. In the latter system, again, the risk of accident from falls of roof is very materially reduced, the ventilation is rendered far more simple and effective, and the labour of the miner, who works in a cooler and purer atmosphere and a less restricted space, more efficient. It thus appears that the system of long wall is that which gives, what is the ultimate object of every working, the greatest possible quantity of coal, in the best possible condition, at the least possible cost.

Existing circumstances may so far modify results as to greatly diminish that superiority, or even to render the adoption of post and stall desirable, if not necessary. The system of long wall is peculiarly suitable to the working of thin seams, but instances might be given where very thick seams have been successfully worked by long wall. A difficulty in working thick seams by this method lies in obtaining the stone or rubbish needed to partially fill up the hollow created by the removal of the coal for the purpose of letting the roof down easily, and without causing damage to the surface. In working the thick seams by long wall in France, first the upper half and afterwards the lower half of the seam are removed, and the space occupied by the coal is partially filled up by stone quarried at surface, and lowered in the coal tubs instead of returning them empty. This method has been adopted to some extent in the Staffordshire Ten-yard Seam. When a seam is divided by bands of refuse, or dirt partings, as they are called by miners, it may, considered only from this point of view, be more favourably worked by long wall than by post and stall, since, in the former system, the refuse may be utilized as pack, while in the latter it must be stowed away against the sides of the excavations, where it serves no useful purpose. A good roof is favourable to long work, but is not indispensable. With management, the system may be successfully carried out when the roof is very weak and jointed. The working face should be pushed rapidly forward so as to be always beneath a fresh or a green roof. If the roof contains ironstone, which can be worked with the coal, whereby a large quantity of refuse is produced, the seam can be worked most advantageously by the system of long wall. On the other hand, if the roof contains a large quantity of water, if the surface is covered with important buildings, or reservoirs of water, or traversed by rivers, streams, canals, or railways, in which cases it is essential not to let the roof down, the system of post and stall is best. In some places, where the workings extend beneath the sea, no other could be adopted. Under such circumstances the pillars are lost, and the workings laid out accordingly. In post-and-stall workings there is also less difficulty in keeping the roadways in a good state, and the system is generally favourable to a large daily output.

If the circumstances of the case have led to the determination to adopt the post-and-stall system, the next question that presents itself is, how to lay out the workings in conformity with the existing conditions. We shall assume, as before, in order to have a typical example, that the seam lies at a slight inclination, and that it is unaffected, in the portion of the field under consideration, by faults or derangements of any kind.

In workings on the post-and-stall system, it is sought to drive the bords at right angles to the cleat; hence the plan of the workings is always so designed as to set off those excavations in that direction. The bords are the principal excavations, the headways being intended primarily for ventilation. As the bords are invariably set off perpendicularly to the cleat, that direction is called bordways; and as the headways are perpendicular to the bords, the direction parallel to the cleat is termed on the ends. Since the main levels are driven in a water-level direction, that is, along the strike of the seam, they may cut the coal bordways, headways, or obliquely, the latter direction being known as cross-cut; and since the bords are to be driven at right angles to the cleat, the direction of the workings relatively to the main levels will depend upon the angle at which these levels cut the cleat.

Let it be assumed, in the first place, that the direction of the main levels is headways, that is, that they have been driven on the ends of the coal. In such a case, the bords will be set away out of the upper level. A barrier of coal, cut through at intervals to form pillars of large dimensions, is left on the rise side of the upper level, to protect these main ways of the mine from the effects of thrust and creep. The thickness of these pillars will be determined by the considerations which affect the shaft pillars, already treated of. The importance of these barriers is great, as any injury to the main levels deranges the ventilation, and seriously impedes the traffic. Again, suppose, on the contrary, that the direction of the main levels is bordways, that is, that they have been driven perpendicularly to the cleat. In this case a pair of drifts is set off from the upper level, at a convenient distance from the shaft, say about 80 yds. These drifts, which are called winning headways, will be similar in dimensions and in distance apart to the main levels, to which they are driven at right angles. From these winning headways the bords may be set off parallel to the main levels.

To determine the dimensions of the pillars, it is necessary to consider the effects of what is known as thrust and creep. Both thrust and creep are occasioned by insufficient dimensions in the pillars, the difference between them being due to the difference of strength in the rock composing the floor and the roof. When the floor and the roof consist of strong unyielding rock, and the pillar of coal left is too small to support the pressure thrown upon it, the pillar cracks, breaks up into prismatic portions, from which large slabs fall off, and finally is crushed and ground into small coal and dust. The yielding of the pillar lets down the roof, the workings become in consequence choked up, and the surface is injuriously affected. This action of the downward pressure is known as thrust. When, on the contrary, the rock composing the floor, or both the floor and the roof, is weak and soft, and the pillar of coal too small, the downward pressure upon the latter causes the floor to rise in the excavations, while the roof, if also of a yielding nature, sinks at these unsupported points. The creep is insidious in its approach, and irresistible in its progress. It may have originated at some unusually weak point; but having once set in, it spreads slowly, but surely, over the whole district. No timbering can arrest nor even, when it has fully set in, materially retard its progress. The roadways have to be continually repaired, at great cost, and the airways become choked up, until finally the labour of keeping these ways in order becomes too great to allow the workings to be carried on at a profit, and the district or the colliery is abandoned. In this way, thousands of acres of valuable coal have been lost.

To determine the minimum dimensions of the pillars requisite to withstand the thrust and the creep, it would be necessary to take into account the strength of the rock in the floor and the roof, the strength of the coal itself, and the pressure of the superincumbent strata. These are problems susceptible of only an approximative solution and of empirical treatment. Experience gained under similar conditions is alone worthy of confidence, and following this experience will lead, for the sake of safety, to excessive dimensions. Thus the minimum dimensions have been left altogether out of consideration, and another principle of working adopted. Wherever it is important that no surface disturbance should take place, the size of the pillars is calculated in the same way as that of the shaft pillars, the base of the calculation in this case being designed to give security by means of a great surplus of strength. The same remark applies generally to the barriers left to protect the main roads from thrust or creep occasioned by the removal of the pillars beyond. In all other cases the pillars are regarded, not as supports to the roof, but as masses of coal prepared for subsequent removal. Hence enormous dimensions are given to the pillars, and by this means the evils of thrust and creep are entirely avoided. As there is nothing but convenience to limit the size of the pillars when viewed as masses to be wholly worked away, in deep pits it is customary to take out by the preliminary workings, that is, by the driving of the bords and headways, only from one-fifth to one-fourth of the coal, leaving pillars 30 yds. long by 18 or 24 yds. broad, and even 40 yds. long by 30 yds. broad. It may be remarked here that long pillars are to be preferred, that is, a pillar 30 × 16, or 30 × 18 yds., is preferable to one 30 × 24 yds. The bords, as before remarked, are usually driven as wide as they will stand, that is, usually from 3 to 5 yds., and the headways, or holings, as the lesser excavations demanded by the requirements of ventilation are commonly called, are about half that width.

It was formerly the custom to open out in bords and headways a whole district, and when the boundary had been reached by the workings of this first stage, to work off the pillars, beginning at the extreme limit, and returning to the point at which the bord workings were commenced, leaving the roof to fall behind the workmen. Sometimes this plan of working was carried out over very large areas, and in such cases, when the first workings had reached the boundary, an extensive tract of broken mine, that is, the portion supported by pillars, was formed. To this mode of proceeding there are several serious objections. By leaving the pillars until the boundary has been reached, an immense number of airways and roadways have to be kept up, and this number is constantly increasing until the limits of the area to be worked out have been arrived at. This circumstance renders the ventilation difficult, and thereby augments in a very considerable degree the liability to accidents. Moreover, the length of time during which the broken mine is left, immensely increases the danger of thrust and creep setting in, by which the whole area may in a short time be overrun. Also, by this method, the pillars first formed are last removed, and hence it happens that a large number of them crack and crumble away under the combined action of atmospheric agencies and great pressure. Even if they resist this action well, the quality of the coal is greatly deteriorated by the long exposure.

For the foregoing reasons, it is now generally the practice to carry on the two workings simultaneously, by making the working off of the pillars to follow closely the opening up of the bords into the whole coal. By this means, the length and the mean duration of the ways are reduced, and the coal is obtained from the pillars in a good condition. The space left by the broken workings is called the goaf, and into it the roof falls. Goaves need careful watching, as they offer favourable conditions for the accumulation of gas, which may be forced out by falls of rock.

The area contained within the boundary to be worked is divided into several independent compartments or districts. This improved method of laying out the workings is due to Buddle, who was also the first to introduce the plan of working off the pillars behind the whole workings. Each district is separated from the others by strong barriers of coal, and ventilated by its own current of air, so as practically to constitute separate mines. The advantages of this arrangement are great and numerous. Suppose, for example, that we have an area divided into four districts; the air entering by the downcast shaft will, on reaching the bottom, be separated into four currents, each of which will be made to pass through one of the districts, and then be conveyed to the upcast shaft. By this means, the miners at the most distant faces of work get the air pure and cool, which would not be the case if it had to pass through the whole area comprising the four districts. Another advantage of the system lies in the isolation of the effects of an explosion. As one district is entirely independent of the others, being enclosed by barriers and ventilated by its own current, the effects of an explosion cannot extend beyond the limits of the district in which it occurs. The importance of this fact will be more fully understood when the subject of ventilation has been treated of. Moreover, by the concentration of the working places in the district, or panel system, the ventilation is greatly simplified and rendered much more efficient, whereby the risk of explosion is very greatly reduced.

In the system of working by long wall, the whole of the coal is, as before observed, extracted at one operation, the roof being allowed to come down as the extraction proceeds. This is the principle of long work, and whatever form the system may assume, it is strictly followed throughout. The mode of carrying out the system may be made to vary widely, in accordance with the different conditions existing in different localities. Long work is susceptible of far greater modification of detail than post and stall. This feature constitutes one of its great merits, and by enabling the system to adapt itself to the varied requirements of different localities, it has contributed largely to its wide and rapid extension.

In long workings, as in post-and-stall workings, it is generally sought to advance across the cleat of the coal, but there are sometimes circumstances, notably that of inclination of seam, which render it desirable to advance the faces of work in some other direction.

Let it be assumed that the main levels have been driven headways in the coal, that is, on the ends. A barrier of coal will be left on the rise side of the levels to protect them from thrust, as in the case of post-and stall workings, though this precaution is not always observed; and beyond this the workings will be carried forward as a straight face, a curved face, or in several lengths of face, according to the conditions of the case, the most important of which conditions is the nature of the roof. If the face is laid out in lengths these lengths are called stalls, and they are kept in advance of each other, to avoid straining the roof along the same line throughout a long distance. It will be observed that, according to this system and method of working, roadways must be made and maintained through the goaf, or, as the exhausted portion is more frequently called in long work, the gob, for the purpose of rendering the faces accessible, and affording a means of conveying the produce to the main levels, and thence to the shaft. These roads are called gob roads, and must be well constructed and maintained, as they serve, not only as roads along which all the produce of the seam has to be conveyed, but also as airways through which the working places are ventilated.

The number of gob roads required will depend very much upon the manner in which the wall face is laid out, and a road is required for each stall when the face is broken up. To save labour in dragging or putting the coal from the several points along the face to the road, the latter is brought opposite the middle of the working stalls, and for the same reason the stall is limited in breadth usually to about 50 yds., so that the extreme distance over which the coal has to be dragged may not exceed 25 ft. To construct these gob roads through the waste or gob, the stone which is extracted with the coal is built up in walls several feet in thickness, to form the sides of the roads. These pack walls must be built up to a height somewhat greater than that ultimately required, to allow for subsidence when the weight of the roof is brought upon them. When the seam is a very thin one, either the roof or the floor, usually the former, must be cut away to give the requisite height to the roads. The material thus obtained will be used for the pack walls in preference to that derived from dirt bands and other partings in the seam, which is generally of a less resistant character. In some instances, a thin rib of coal has been left to form the road wall on each side, but the expedient has not proved sufficiently successful to warrant its adoption.

The maintenance of the roads frequently offers considerable difficulties and entails great expense. When the weight of the superjacent beds of rock is brought to bear upon the pack walls, the floor, if weak, is apt to rise, the action of the pressure producing the creep which has already been described. In such a case, the roads have to be repaired at night, by men set apart for that purpose. Sometimes the walls sink beneath the weight of the overlying rock, and the height is reduced by the descent of the roof. This circumstance renders it necessary to frequently cut away the roof, so that, after a time, the road may be wholly in the roof rock.

In order to avoid the difficulties and expense of maintaining the gob roads, which are continually increasing in length as the workings advance, there is another method, that of working home, differing from that which we have been considering, and which is described as working out. In this method the roads are kept in the solid coal, so that they are not exposed to the destructive action of a falling roof, as the gob roads are. Moreover, instead of continually increasing in length as the working proceeds, they, on the contrary, are continually decreasing as the wall face advances. This is an advantage which the method of working home was designed to gain.

In laying out workings according to this method, the roads are first driven out through the solid coal to the boundary, and the wall face is then laid out in the manner described for working out. The coal is then worked back towards the shaft, leaving nothing but waste or gob behind. The exhausted portion is in this case entirely abandoned when the coal has been extracted, and the roads, being in solid coal, require but little attention. When the workings are to be laid out according to this method, the preliminary operations will occupy a longer time than when it is intended to work out, and this difficulty often constitutes an insuperable obstacle to the adoption of the method, especially where the proprietary is not well provided with capital.

In the foregoing examples, it was assumed that the main levels coincided in direction with the cleat of the coal, and that it was desirable to give the same direction to the wall face, that is, to advance across the cleat. The workings were therefore at once laid off from the main levels. But if it be desired to advance in the same direction when the levels are headways or across the cleat, the wall face will have to be set off at right angles to the levels. In this case, a pair of winning headways may be driven out from the main levels in the direction of the face, in the manner described under the head of post-and-stall workings, and from these the workings may be laid out. The inclination of the seam will often render this mode of proceeding desirable or even necessary. In some districts, instead of driving these principal gate roads through the coal, and leaving barriers to protect them, the whole of the coal is extracted, and the roads packed with gob or refuse. This method is sometimes applied even to the main levels of the mine, leaving only the shaft pillars as solid or whole ground.

In long-wall, as in post-and-stall workings, the system of division into districts is followed. The advantages to be derived from dividing the area into several distinct and independent portions will be, in the main, identical in both cases. These districts will occupy the same relative positions as in the post-and-stall workings, and they will be served from the shafts in the same manner.

In the foregoing considerations and descriptions, it has been sought to give a clear understanding of the two systems of working coal, and a full appreciation of their respective merits and defects. To attain this end, the general and distinctive features of each system have alone been brought forward, and these have been illustrated by typical cases. It has been already pointed out that these features are subject to great modifications, in compliance with the requirements of varying circumstances. Such modifications, however, and the conditions which determine them, have been left out of consideration here, in order to avoid confusion.

To explain the various operations involved in sinking a shaft, a pair of circular shafts may be assumed, one to serve as a downcast, the other as an upcast. As the operations in each will be similar, it will be sufficient to consider those in the downcast. The advantages of sinking both shafts simultaneously are that the seam is reached through the two shafts at the same time, and the immediate opening out of the underground workings facilitated, the water encountered is more easily dealt with, and one provision of tools, machines, and surface erections is sufficient.

The preparatory work consists in providing the tools and other mechanical appliances, the materials of various kinds, and the buildings that will be required in the progress of the sinking. The tools chiefly required will be picks and sinking shovels suitable for working in rock, the stone-blasting gear, and wedges for dislodging jointed or fractured rock, with rock-boring machines—when these are to be employed—together with the air-compressors, and appliances to be used with them. Besides these tools for dislodging the rock, there will be required corves or kibbles for raising it to surface. It was formerly the custom to construct these sinking corves of wicker-work, well-seasoned hazel being used for this purpose. The capacity of one such corf was about 20 gallons. Corves have been almost entirely superseded by kibbles, constructed of wooden staves bound together by iron hoops like a small cask, and provided with a handle or with three ears to which chains may be attached, to form a kind of bucket. When of small dimensions for well sinking, it is called a sinker's bucket. This form of kibble, much used on the Continent, is made larger in the middle to cause them to sheer off from each other should the ascending and descending kibbles come into contact. For the same purpose, the edges of the hoops are chamfered off. As the canting of the loaded kibble pours the contents down upon the sinkers, it is a danger to be avoided. In England, the sinking kibble is commonly constructed of iron, and its form is similar to that adopted for the wooden barrel-shaped bucket. The kibble is attached to the rope by a spring hook, and is raised at first by means of a common windlass with two handles. Besides these tools, a supply of curbing and planking should be provided for the support of the sides of the shaft.

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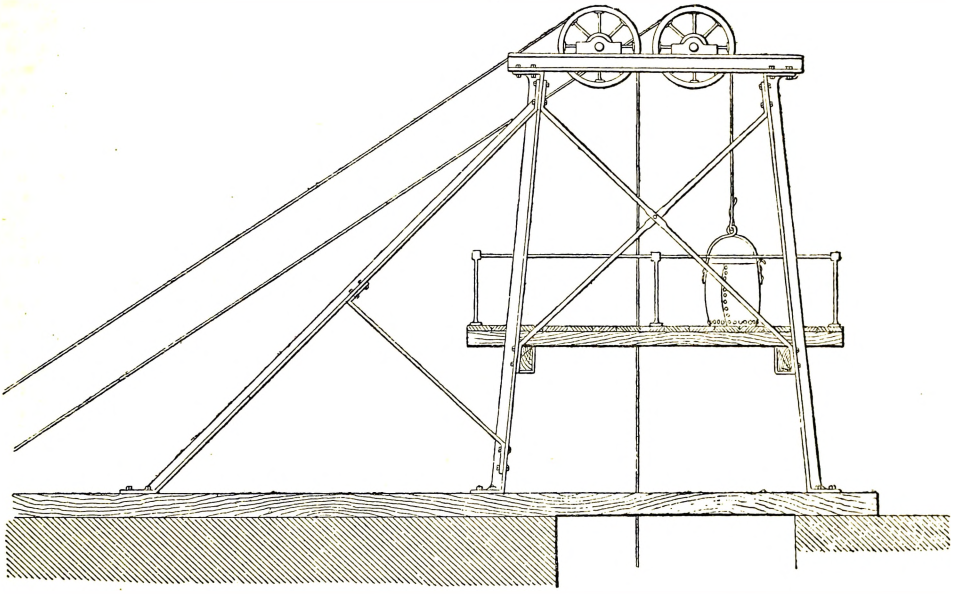

The surface erections required, besides those of a permanent character, are, a carpenter's shed, a smithy, an office for the master sinker and others in charge of the work; a sinkers' lodge, for drying the sinkers' clothes and other purposes; a shed to store the materials required; and a magazine to contain the explosive substance to be employed. As nearly the whole of these buildings will be required to remain as parts of the surface works, their situation relatively to the shaft and to each other should be chosen rather with a view to subsequent convenience than to immediate exigencies. When all of those buildings which will be required during the progress of the sinking have been erected, the engine houses may be commenced, and their construction carried on during the sinking of the shafts. Generally the winding engines will be situate between the two shafts, so as to draw from both.

The operations of sinking will be begun by determining the point to be the centre of the shaft, and striking from this centre a circle having a diameter 2 ft. greater than that which the shaft is to have when finished. When this has been done, the excavation of the soil will be commenced with the pick and the shovel.

The firm rock to be met with after the clay has been passed through is termed the stone head. As the excavation during this portion of the sinking is through soft rock, the pick and the shovel will be the only tools required. The stuff will be raised to surface in kibbles by means of the ordinary jack-roll, and tipped, or, in miners' language, teemed around the mouth of the shaft. Attention must be given at the commencement of the excavation, and continued throughout the whole of the sinking, to the preservation of the verticality of the shaft. This must be preserved throughout the subsequent operations of timbering, walling, and tubbing, care being taken to place these supports everywhere in exact accordance with the centre of the shaft. To ensure this verticality to the excavation, frequent and careful use must be made of the plumb-line. In rectangular and polygonal shafts, a plumb-line should be suspended in each angle; and in circular and elliptical shafts, at the four extremities of the two diameters crossing each other at right angles, in the former, and at the extremities of the major and minor axes in the latter. If the section is large, lines may be required at other points. These suspended lines will be lowered as the sinking progresses, and from time to time other lines will be dropped, in the same positions, from the surface to near the bottom of the excavation. All irregularities rendered apparent by this plumbing must be carefully removed.

During the sinking to the stone head, the sides of the shaft cannot be left without support. There is a tendency in soft rock to swell and to close up the excavation. When this swelling has once begun, its progress is rapid, the motion produced in the rock being an accelerated one. Hence it becomes necessary to prevent the swelling action from setting in, by placing a sufficient support to the sides of the excavation as the sinking progresses. This support consists, for circular shafts, of rings formed of segments of wood, called curbs or cribs, placed at intervals in the shaft, and backed with deal planking. The curbs should be of oak or elm, and their dimensions should be proportioned to their diameter, and to the degree of pressure likely to be brought upon them.

These dimensions will vary from 4 to 6 in. square. Care should be given to their construction in order to bring the ends of the segments to bear evenly upon each other, and to make the joints radiate truly from the centre. The best mode of forming the joint is that in which the ends of two contiguous segments are made to bear against each other in one vertical plane. When jointed in this way, the segments are prepared at surface with the curved wooden fish-pieces or cleats, and sent down the shaft ready to be put together. The backing deals used with the curbs should be about 1 in. in thickness, and about 6 ft. long; a greater length, say by 9 ft., may be adopted. The first length of backing deals set should, in every case, be 9 ft. There should be always ready at hand a sufficient number of curbs, and an ample supply of the planking required to be used with them.

In the case of a shaft of 13 ft. diameter, the curb may be 5 in. square in section, and when put together it should have an inside diameter of 13 ft. 9 in. When the excavation has reached a depth of 6 ft., the first curb is sent down in segments, and put together and placed in position at the bottom. The 9-ft. backing deals are then placed vertically behind the curb, their ends passing down to about the middle of the thickness of the latter. If the ground to be supported is very weak, the backing deals must be placed close together; in fairly strong rock, they may be set at small intervals apart. The distance to be allowed between the curbs will be determined by the pressure from the sides of the excavation. If that pressure is very great, the interval should not exceed 2 ft., or in some cases even less than that distance. Instances are on record in which 6 in. could not be exceeded. A common distance, however, is 3 ft. A second curb having been sent down, and put together upon the first, is raised to a height of 3 ft. above the latter, the height being measured from centre to centre, and the curb supported by a few upright props called punch props. A third curb is then put together upon this second one, and, having been raised 3 ft. above it, is supported by props in the same manner as the second. A fourth curb is put in at the top of the backing deals, and supported in the same way as the others. This last curb will be situate at the height of 3 ft. above the surface of the ground. The object of this elevation is to obtain a height for tipping the stuff drawn from the shaft. The curbs inserted in this manner are next strung, or hung together vertically by means of thin deal planks, or stringing deals. These stringing deals are nailed against the inside of the curb, so as to suspend the latter one from another, and the whole may be suspended from balks of timber at surface by means of the stringing deals.

When the curbing of the excavation has been completed, the sinking may be resumed, and continued another 6 ft. This part of the excavation is not, however, extended to the full diameter; but the sides are kept in a line with the inside of the curbs. This is necessary in order to leave a support for the latter. When the depth of the second 6 ft. has been reached, the excavation is shorn out to the full diameter, and a level bed provided for the reception of the next curb. This is sent down in segments, as before, put together, and placed in position at the bottom. The sides are then shorn out up to the first curb laid, that is, the lowest curb of the first set, and the 6-ft. backing deals put in behind this curb and the one just laid. Another curb is sent down, put together upon the bottom one, and raised upon props to a height of 3 ft., that is, midway between the curb last put in, and the lowest of the first set. Upon this curb, props are set to support the one immediately above it, and the stringing deals are nailed on to hang them all together. The whole length of curbing should be slung by means of the stringing deals to balks of timber at surface. This is necessary to prevent the curbing from slipping down when the support is removed by shearing out the sides from under them. The deals may be suspended from the timbers forming the temporary staging required around the mouth of the shaft for convenience in drawing and tipping the rubbish. When the second 6 ft. of excavation has been curbed, the sinking will be again resumed, and continued through the third 6 ft., which length will be curbed in the same manner as the preceding. These operations will be repeated until the stone head is reached.

When the stone head has been reached, another set of operations has to be performed. The support afforded by the curbing is intended to be only of a temporary character. The continued pressure of the sides of the shaft against this support would, in a short time, cause it to yield, and when the sides have begun to run, the destruction of the shaft is almost inevitable. Hence it becomes necessary to replace the timbering by masonry, and the substitution should be made as soon as possible. In general, the walling cannot be built until a firm rock foundation has been reached. It is desirable to push on the sinking to this point with all possible speed, in order to escape the danger of the timbering giving way.

On reaching the stone head the excavation is reduced in diameter, and the sinking is continued until the rock has become sound and strong. When this point has been attained, the sides are shorn back to a greater diameter; in the case assumed, say to a diameter of 15 ft. 9 in. It is now required to prepare the foundation for another curb of larger dimensions, upon which the walling is to rest, and called on that account the walling curb, or sometimes, from the method of fixing it, the wedging curb. This curb may be either of metal or of wood. Sound and well-seasoned oak is commonly employed. When iron is used, the curb is open on the inner side. The oak wedging curb will be 13 in. on the bed, as the walling is to be of brick, and 6 in. in depth; its inner diameter will, of course, be that of the shaft, namely, 13 ft. The rock bed upon which this curb is to rest must be carefully levelled, so as to give it an even bearing at all points. Some ½-in. fir sheathing is then laid upon this bed, and the curb laid upon the sheathing. Before proceeding to fix the curb, it must be ascertained that its centre coincides exactly with that of the excavation. When the curb has been placed accurately in position, a backing of fir, about 2 in. thick, is put in vertically between the outside of the curb and the sides of the shaft, and firmly wedged. The wedging must be performed simultaneously at opposite points in the curb, and it must be continued until no more wedges can be driven in. The greatest care must be exercised during these operations to avoid displacing the centre of the curb. When iron curbs are used, a piece of oak sheathing is placed between the joints; the thickness of this sheathing should diminish from the outside of the curb inwards. As the pressure thrown upon the curb by the wedges tends to lift the former from its bed, this tendency must be counteracted by props set upon the joints of the curb, and abutting against the rock above.

When the walling curb has been securely fixed, the walling of the shaft may be proceeded with. In most cases, the walling will consist of bricks, which is the cheapest material available, and sufficient for the purpose under all conditions. Frequently these bricks may be made on the spot from the clay necessarily excavated for the surface works. It is essential that the bricks used in the walling be moulded to the form required by the shape and diameter of the shaft. The mortar should be of the best quality and slightly hydraulic in character. In walling through wet strata, quick-setting cement will be required.

Sometimes stone masonry is adopted for the walling of a shaft. Stone of a schistose structure is rapidly disintegrated by the action of atmospheric agencies, and is unsuitable for walling purposes. Sandstone and limestone may be employed; but the former is somewhat difficult to work, and the latter is usually costly to obtain. In stone walling, the blocks should be of moderate dimensions, and, as nearly as practicable, uniform in size. Very small blocks involve the use of a large quantity of mortar, and very large blocks are difficult to work and to handle; while the mingling of large and small blocks occasions an unequal distribution of the pressure. Each of the blocks should be tooled upon five of its faces, that which is in contact with the rock being alone left in a rough state. The two side faces should be prepared with special care, to ensure a close joint, everywhere coinciding in direction with the radius of the shaft.

Bricks constitute a more suitable and a cheaper material for shaft walling than stone. The clay of which they are made should be rich in alumina, and entirely free from lumps of calcareous matter. If the clay is not sufficiently rich in alumina, the bricks will be porous and crumbly; on the other hand, if too rich, they are apt to run during the process of manufacture, and are too smooth to hold well to the mortar. Fireclay is an excellent material for walling bricks, and in some localities it may be procured nearly as cheaply as ordinary clay. Sometimes this material is employed moulded into blocks to the required form. The dimensions of such blocks commonly are 24 in. by 9 in. by 6 in.

The thickness of the walling will be, in some degree, determined by the pressure likely to be thrown upon it. Thus, in passing through compact rock, a single brick may be sufficient, the object of the walling in such a case being rather to protect the rock from atmospheric influences, and to prevent the fall of detached portions, than to resist a pressure from the sides. In loose rock of a fairly strong character, a thickness of 13 in. will suffice; and in very unstable rock, or where there is a very great pressure of water, 18 in. or more may be necessary. In the assumed example, the wedging curb is designed for a walling of 13 in.

When the wedging curb has been securely fixed, the walling is commenced upon it, as a foundation. Until a shaft is walled, it is exposed to the danger of closing in, and therefore no exertion should be spared to complete the walling in the shortest possible time. The walling will have to be performed from a staging or scaffolding, capable of being raised as the work progresses. The staging or cradle adopted for this purpose is circular in form, and is a simple wooden construction, consisting of 2-in. planking nailed upon timbers. Through these timbers stout bolts, with a ring attached, are passed, and secured on the under-side by means of a nut. From these rings the cradle is suspended, by means of chains attached to two ropes, from two winches at surface, one on each side of the shaft. Later, when the surface arrangements are more complete, the cradle will be suspended by one rope. This rope must possess a wide margin of strength, and must undergo frequent and careful inspection. It should be 10 in. in circumference. The diameter of the cradle should be such as to leave a space of about 4 in. between it and the shaft. This space is necessary to ensure the ventilation of the shaft below the staging. When a seam of coal is near the bottom of the shaft, or has been entered or passed through, this precaution is essential. Sometimes, besides the space around the staging, a hole is provided in the centre of the latter to allow the gas to pass up; through this hole the tub dips into the sump. In spite of the precautions, the accumulation of gas beneath the staging is one of the most fruitful sources of explosion of firedamp.

As the walling proceeds, the timbering immediately above it will have to be removed, and care must be taken during the removal of this portion not to materially weaken that which is left. If the pressure against the timbering is great, a small portion only of the latter can be taken out at a time, and the remainder must be securely stayed. The curb immediately below which the timbering has been taken out must be supported by vertical punch props set upon the walling beneath, and when the pressure is great, by props placed horizontally or raking props in an inclined position against the sides of the shaft. Under some difficult circumstances, it may be necessary to build portions of the timbering into the walling; but this should be avoided wherever possible, as the rotting of the wood endangers the masonry.

The hollow between the walling and the rock must be filled with clay, carefully rammed to form a solid backing, or better, with concrete. This is necessary to distribute the pressure equally over the masonry, and it cannot be neglected without risking safety. It is also essential to provide for getting rid of the water which oozes out from the sides of the shaft, by an outlet beneath the lowest course of the walling. Either an iron pipe is built into the bottom course, or a horizontal hole is bored with an auger in the wedging curb itself, which hole is made to communicate with the space between the walling and the rock, through another vertical hole bored near the outside of the curb and left uncovered by the masonry. The outlet thus provided for the water is kept in communication with the space above the backing by means of a triangular channel formed by two pieces of board, or by a vertical pipe of small diameter, and pierced with holes, which is lengthened as the walling rises. In putting in the backing, care should be taken to make the upper surface incline towards this outlet for the water. When the walling is completed and the sinking recommenced, the outlet may be plugged; or if the quantity of water is considerable, flexible tubing may be affixed to it, to conduct the water down to the sump, and so prevent it from dripping upon the sinkers.

A similar arrangement is adopted for collecting and conveying away the water that soaks through the walling. This water, which trickles down the sides of the shaft, is stopped and collected at one of the wedging curbs in the following manner. The first three or four courses of brickwork upon the curbs which are to serve this purpose are inset for the purpose of leaving a portion of the upper surface of the curb exposed. In this portion of the curb, a groove is cut, so as to form a channel round the shaft. The water which runs down the face of the walling collects in this channel, and is discharged through a hole, bored obliquely in the curb, into a small pipe through which it is conveyed either to the sump or to a tank from which the pump takes its water. Sometimes, instead of using the wedging curb for this purpose, a wooden curb of smaller sectional dimensions is built into the walling.

The shaft walling is continued up from 5 to 15 ft. above the surface of the ground. The object of elevating the mouth of the shaft is to obtain a good lead for the removal and the discharge of the stuff first raised from the excavation. The manner of terminating the walling and of fitting up the mouth of the shaft varies in different localities, according to the method of receiving the loaded kibbles. In the north of England, a kind of coverign or staging of wood is fixed to partially cover the shaft. To prevent the ascending kibbles from striking against the under side of this staging, deals are nailed diagonally against the edge of the staging and a bunton fixed against the sides of the shaft. These deals are called striking or sliding deals. When the loaded kibble is raised to a height a little above the staging, a tram is run out to the edge upon rails laid down for that purpose, and the kibble is lowered upon it. The loaded kibble is then detached from the spring hook, and an empty one substituted for it. To facilitate these operations, the rails should be laid with a slight inclination from the mouth of the shaft, and this inclination is also needed to prevent the tram striking heavily against the sill or edge of the shaft.

In some other coal districts, the manner of receiving the loaded kibbles and the laying out of the shaft mouth are different. This difference will be best understood from a description of the surface arrangements of a shaft in South Staffordshire. The walling of this shaft was carried up to a height of about 15 ft. above the surface of the ground, and thick brick walls erected to enclose the shaft. An inner wall, contiguous to the shaft, forms with the outer walls a rectangular brick foundation for the head-gear. The walls enclosing the shafts carry balks of timber to form a staging on a level with the top of the pit walling. Upon this staging are laid light tram rails, on which runs a wooden tram or movable platform. This platform is of sufficiently large dimensions to completely cover the mouth of the shaft, when it is run over the latter, and a rail is laid on each side of the shaft to allow the tram to run over. A fence is fixed to one end of the tram platform, and supported upon two small wheels running upon rails on the opposite side. During the drawing, the fence stands over the mouth of the shaft, and when the load has been raised a little above the level of the platform, the latter is run forward completely over the mouth of the shaft. The load is then lowered and deposited upon the platform. When the loaded kibble has been removed from the spring hook, and an empty one attached, the latter is raised, and the platform is then run back with the loaded kibble. At the same time, the fence returns over the mouth of the shaft. This particular arrangement of the platform and fence was designed with a view to the ready removal of the water raised in tubs from the shaft.

When the walling has been completed, a strong and convenient head-gear must be erected to continue the drawing of the stuff on the resumption of the sinking beneath the walling. In connection with this head-gear, a steam engine will be required to draw the rubbish and the water from the excavation. Fig. 852 is of an arrangement common in the Chesterfield district. Since the introduction of the winding engine of the locomotive type of construction, no strong foundations or buildings are required beyond a light shed.

The sinking having reached a point at which moderate quantities of water will be met with, means must be provided for draining the bottom of the excavation. The streams of water which enter the excavation through fissures in the rock are called feeders. Surface feeders are such as are in direct communication with the surface; these, of course, are influenced by the weather. Partial feeders are those which are in communication with a cavity containing water; they gradually decrease after being opened, and in time become entirely exhausted. Permanent feeders are such as derive their water from inexhaustible sources, and therefore continue without diminution. The smaller quantities of water that escape from the strata into the excavation must be raised to surface either in tubs or by pumps. The method of drawing the water in tubs is sufficient whenever the quantity of water is not great. Even when the quantity is considerable, it may be advantageously removed by this means, for winding is a far cheaper mode of raising water than pumping.

The tub commonly used for drawing water is of iron, and is similar in shape to the kibble. The capacity of these tubs is frequently about 100 gallons, when it is intended to draw by the engine. The tub is suspended by a bow turning on two pins placed a little below the centre of gravity, on the outside of the tub. Besides the larger bow which turns upon the pins forming the points of suspension, there is a smaller one fixed to the tub, and passing freely beneath the former. On one side of the tub is a spring catch, which, by laying hold of the larger bow, prevents the tub from tilting in the shaft. When the tub is raised full of water to the top of the shaft, the waiter-on seizes the smaller bow, and, releasing the spring catch, pulls the tub over, discharging the water into a shoot, by which it is conveyed away. The position of the centre of gravity above the axis upon which the tub turns renders the operation of tipping an easy one.

The objection to this form of tub, that it has to be filled from above, may be removed by constructing it with a valve at the bottom, through which the water can enter. When the tub is lowered into the water, the pressure of the latter forces up the valve, and the tub fills. When the tub is full, the valve drops upon its seating, and retains the water. To empty the tub, it is lowered on to a trough, when the projection of a spindle coming in contact with the planking, the valve is forced up.

When the excavation has attained the depth of from 15 to 20 yds., means must be provided for directing a sufficient current of air down to the workings. The air-box will for some time give an adequate ventilation; it consists of a wooden pipe, generally about 12 in. square, outside dimensions, made of 1-in. or ¾-in. deal boards, the joints of which fit truly, and are tarred or pitched to render them fairly air-tight. This pipe is fixed against the side of the shaft, and carried down to near the bottom. In order not to encumber the mouth of the shaft, the pipe, within a few feet of the bottom, is passed through the walling, and carried in an inclined direction to surface, at a convenient spot a few yards distant. Over the aperture of the pipe at this spot a chimney is roughly built of bricks, in which a fire is kept burning, or into which a steam jet is turned, or instead of erecting this special chimney, the pipe may be put into communication with one already existing, the engine stack, for example. As the lower end of the pipe cannot be brought close down to the workings by reason of the danger to which it would be exposed from the shots, a flexible canvas tube, called a bag, is attached, which is dropped lower as the sinking proceeds. It will be necessary to keep a considerable current of air passing through this pipe; for besides the large quantities of powder smoke that have to be carried off, carbonic acid gas, or choke damp, may exude from the joints and fissures in the rocks; and in passing through thin seams of coals, or on approaching the thicker seams, blowers of inflammable gas may be met with.

When the depth of the shaft has become great, or earlier if the rock is foul with gas, the foregoing method of ventilation will be found insufficient, and recourse must then be had to the plan of bratticing the shaft, that is, of dividing it by a wooden partition, called a brattice. The purpose of the bratticing is to divide the shaft into two unequal air-tight compartments, the larger of which, devoted to the drawing of the stuff, may serve as a downcast, and the smaller, reserved for the pumps, as an upcast. The arrangement is of the same nature as that of the air-box, but the difference is that the brattice gives a very much larger airway than the box. When the brattice has been put in, the ventilation will proceed naturally, the current descending on one side, and ascending on the other side of the brattice. Under such conditions, however, the air current will not always descend through the same compartment, the direction being dependent upon external causes, as the direction of the wind, and the existence of objects affording shelter. When this natural ventilation has become insufficient, the top of the smaller compartment is planked over, and the space below placed in communication with a chimney, through an inclined passage, as in the case of the air-box, or with a small fan.

There are two methods adopted of constructing the bratticing, one known as the bunton system, and the other as the plank system. In the former, deal battens, 7 in. × 3 in. in section, are fixed against the sides of the shaft, one on opposite sides, from the top to near the bottom. As these side or stringing planks are to form the support for the bratticing, they must be firmly fixed to the shaft. The method of fixing them is to drill holes in the walling to a depth of not less than 12 in., and to plug these holes with wood to give a sufficient hold for the spikes. Where the shaft is lined with metal tubbing, the planks are spiked to the joints of the tubbing. At intervals of 3 ft. from centre to centre, the stringing planks are provided with notches to receive the ends of other battens or the buntons, placed horizontally from stringing plank to stringing plank across the shaft. These buntons are fixed to the side supports with nails, and are intended to support the cleading or sheathing which is to constitute the brattice. This cleading consists of fir boards from 1 to 2 in. thick, according to the character of the bratticing, whether temporary or permanent, nailed vertically upon the buntons. These boards are planed true on the edges, so as to form air-tight joints, and in nailing them in position care is needed to keep the joints close. When the brattice is to be permanent, a thin strip of wood or sliver is inserted into a groove ploughed in the edges of two corresponding boards.

The plank brattice is of more simple construction, and is to be preferred as a permanent structure. In this system of bratticing, two side planks are used upon each side of the shaft, placed at an interval of 3 in. apart, and the buntons are dispensed with. The brattice boards are 3 in. thick, and are placed horizontally, edge upon edge, by being slid down the grooves formed on opposite sides of the shaft by the side planks. The joints in this kind of brattice are kept firm and air-tight by planing the edges of the boards true and dowelling them with iron dowels, or preferably by means of oak slivering. When iron tubbing is used, the latter is cast with grooves to receive the boards, in order to dispense with the stringing planks. Whatever the nature of the bratticing, it must not be carried, during the sinking, nearer to the bottom than 20 ft., because of the injury which might be caused to it by the firing of shots. Another precaution is to secure the brattice from injury by the ascending kibbles, and consists in placing beneath it, at intervals apart so as not to materially impede the ventilation, sliding deals, similar to those placed beneath the covering of the shaft at surface.

On resuming the sinking beneath the walling, the excavation is carried down in a line with the inside of the wedging curb for a distance of about 3 ft., and from that point gradually enlarged to the full diameter. This enlargement should be proportioned so as to make the sides of the excavation, from the point at which the enlargement begins to that at which it terminates, form an angle of about 60° with the horizontal. By this means a kind of bracket is left for the support of the walling. Beneath this bracket the excavation is continued down of the full diameter. When a depth has been reached at which walling becomes necessary, a wedging curb is laid, and the walling is built upon it, till the lower portion of the rock bracket is arrived at. This bracket is then cut away in small portions at a time, and the walling carried up to the under side of the wedging curb. During this part of the work, it will be necessary to support the wedging curb of the upper length of walling, at the points from which the rock has been removed, by vertical props set upon the lower walling.

This portion of the sinking being in compact rock, the excavation will be carried on by means of blasting. The details of these operations have been described under the head of Blasting. The procedure in shaft sinking is precisely that followed in a heading, and the first operation consists in unkeying the face, effected by angling the shot holes. The unkeying is from the centre of the face, that is, the bottom of the excavation. When the strata are highly inclined, however, it is better to unkey from one side of the excavation. The water which flows into the workings must be collected into one place, both for convenience in raising it, and for the purpose of keeping the surface of the rock clear for the sinkers. The depression caused by the removal of the key serves for the purpose of collecting the water, and is called on that account the sump, or well. Into this sump the tub dips, or, if pumps are used, the suction hose is dropped. When the rock beds are highly inclined, the water gravitates towards the dip side of the excavation, and it therefore becomes necessary to place the sump in that situation. The unkeying of the rock from this direction is, moreover, favourable to the action of the shots under the conditions of highly inclined beds. In putting in the shot holes, care must be taken not to terminate them in, or nearly in, a bedding plane, because when so situate the force of the charge expends itself along this plane.

When the shot holes are bored by machine drills, the most favourable position for the holes cannot always be adopted.

The blasting, especially if the shot holes have been bored by machine drills, leaves the sides of the excavation in a very rough state. These will, therefore, require to be subsequently dressed down by hand with the pick and the wedge.

The sinking and walling of the shaft will be continued through the rock until water-bearing beds are met with. Down to this point all the infiltering water has been raised to surface, without much difficulty, in tubs, or by means of small pumps. But when heavy feeders are met with, it becomes important to stop them back. This is accomplished by a water-tight wooden or cast-iron lining, called tubbing, which is fixed in the shaft throughout that portion which passes through the water-bearing beds. Brick walling has been applied as tubbing, but is not suitable, and is very rarely used. Wooden tubbing, in England, has been almost entirely abandoned in favour of cast iron. It is, however, still very commonly adopted on the Continent of Europe, and where timber is plentiful. It is therefore desirable to describe this kind of tubbing, and the method of fixing it in the shaft, particularly as many of the operations of fixing the tubbing are identical for both kinds.

The sinking beneath the last wedging curb supporting the walling is carried down a few feet in a line with the inner face of the curb, to form a support for the latter, and then gradually laid off to the diameter, in the case assumed, of 15 ft. 6 in., for metal tubbing; and to about the same diameter for wooden tubbing. From this point, the sinking should be carried down through the permeable bed to the impervious bed beneath with all possible speed. When a water-bearing is pierced, the water, which is often under great pressure, issues in great abundance into the excavation, and this abundance increases as the water clears itself a passage through the interstices of the rock. When the impervious bed has been reached, the sinking will be brought into its net size of 13 ft., and continued down till a good foundation is found for the wedging curb. At this point, the sinking, after being carried down 4 or 5 ft. farther to form a sump for the water, will be shorn back to receive the wedging curb. The latter is of oak, and similar to that used for the walling, but of somewhat larger sectional dimensions; the joints require to be fitted with greater care, thin slit deals being placed between them, and the rock bed must be prepared and levelled with perfect accuracy for its reception. As the wedging has a tendency to lift the outer edge of the curb, the bed should have a slight inclination outwards, so that the upper surface of the curb may be perfectly level when the wedging is completed.

When laid in position, the wedging curb should be everywhere about 2½ in. from the sides of the excavation, so as to leave an annular space of that width between it and the rock. Care should be taken to see that the rock be perfectly sound in this part; if joints or small fissures exist, they must be well stopped with clay, or, in some cases, caulked with oakum. A fir sheathing 1½ in. thick is placed next the curb in the annular space between it and the rock; the breadth of this sheathing is a little greater than the depth of the wedging curb, so that when in position it stands a little above the latter. When the shaft is circular, saw-cuts at every 3 in. across the sheathing, that is, at right angles to its length, will be required, to enable it to adapt itself readily to the shape of the curb. The fir sheathing is forced into close contact with the curb by means of wedges driven in at intervals, and the space between it and the rock is filled in with moss or with oakum. The moss must be forced in until it is incapable of further compression, when the wedges will have to be withdrawn, and their places also filled with moss. The prop, which is set upon the joint of the curb, and made to abut against the rock above, is needed to prevent the curb from rising during the operations of wedging.

The curb is now ready for wedging, which is performed in the following manner. Between the curb and the sheathing, carefully prepared wedges are driven in, to force the sheathing and the moss behind it firmly back against the rock, so that the curbing, when finished, shall make a perfectly water-tight joint. The wedges are of soft wood; poplar, where this is readily procurable, as in France; and fir in other localities. It is essential that these wedges be uniform in dimensions. In form, those first applied will be broad and flat; afterwards narrower wedges of a pointed form, called spiles, will be required. The flat wedges are inserted close together all round the curb, the edge being slightly driven in to keep them in position. When all the wedges are inserted, they are driven in as equally and as nearly simultaneously as possible. The next operation is to double the wedges. An iron wedge, of greater thickness than the wooden ones, is driven in for the purpose of loosening the wooden wedge next to it, by taking the pressure from the sheathing. When this wedge is freed, it is taken out, and another one substituted for it, head downwards. A second wedge of the same dimension is then inserted, point downwards, between the upturned point of the first and the sheathing.

When the wedging has been completed up to this point, a quadrangular iron wedge, steeled at the tip, is driven in successively between the flat wooden wedges, for the purpose of inserting the point of a fir spile. These spiles are driven into the interstices between every two wedges, until they refuse to penetrate farther. When these are all driven down, the whole of the curbing is tightly wedged in all directions, and the moss has become so compressed as to be hardly visible; the heads of all the wedges and spiles are then adzed down. Next, the heads of all the flat wedges are cleaved with a steel-tipped iron wedge, and oak spiles, previously well dried in an oven, are inserted in the cleft, and driven in as far as they will go. The operation of cleaving the wedges is continued as long as a spile can be made to enter. When no more can be got in, the whole is adzed down to a level surface, and the curbing is then complete. Sometimes three such curbs are laid; but commonly there are but two. It is important that the wedges should be put in dry, because when in that state their dimensions are at a minimum, and by swelling, on exposure to moisture, they still further tighten the joint. It is for this purpose that the last wedges inserted are dried in an oven. Precisely the same method of fixing the wedging curb is adopted when the shaft is polygonal, as frequently on the Continent.

When the wedging curbs have been laid, the tubbing is built upon them. This tubbing consists of wooden curbs, constructed similarly to the wedging curbs, and built up one upon another throughout the whole length of the shaft to be tubbed. These curbs are generally about 8 in. broad on the bed, and 10 in. in depth. They need not be all of the same depth, and their thickness will be determined by the pressure which they will be required to support, and will, therefore, diminish as the tubbing rises towards the surface. The beds of the curbs should be truly dressed, in order that a water-tight joint may be made subsequently by merely caulking it. When the height of the tubbing is considerable, a broader curb, called a bearing curb, is put in at intervals of 8 or 10 yds., and firmly wedged against the rock. These bearing curbs take the weight of the tubbing off the wedging curbs at the bottom. The space behind the tubbing is filled up with strong concrete. This concrete backing penetrates into every hollow and fissure, and on hardening it forms a strong protective casing around the tubbing. The existence of such a casing greatly facilitates the operation of replacing a faulty curb after the completion of the shaft.

In the case of iron tubbing, the wedging curbs are of cast iron, and hollow, sometimes open on the outside and sometimes on the inside, and divided at intervals by partitions to give strength to the curb. The hollows between these partitions are filled with oak. In some cases, the curb is not open on either side. Generally, these curbs are about 13 in. broad, and 6 or 7 in. in depth, the thickness of the metal being about $1\frac{1}{4}$ in. Cast-iron curbs are put together in segments, and laid upon a bed of $\frac{1}{2}$-in. fir sheathing. Oak sheathing is inserted between the joints, which are made firm by wedging. This sheathing should be cut and placed in such a way that the grain may run towards the centre of the shaft, and it should be made to taper from the outer towards the inner face of the curb, say from a thickness of 1 in. on the outside to $\frac{5}{8}$ in. or $\frac{1}{2}$ in. on the inside. The method of fixing the iron wedging curb is the same as that adopted for the wooden curb. Sometimes a wooden wedging curb is first laid, and an iron one then laid upon it; more frequently, two iron curbs are laid one upon the other.

The plates of the tubbing, like the wedging curbs, are cast in segments, the dimensions of which require from eight to twelve to form a circle of tubbing. These segments vary from 12 in. to 36 in. in height, according to the pressure they are to withstand, and from $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. in thickness. They are smooth on the inside so as to form a regular surface in the shaft, but on the outside, next the rock, are strengthened by ribs and flanges, supported by brackets. These flanges form the edges of the segment, and they should be cast perfectly true, so as to form a regular joint when two segments are brought into contact. The top and one of the side edges are provided on the outside with a projection or flange, to retain the joint sheathing and two adjoining segments in their positions. Every segment has a hole in the middle, to allow the water to escape during the operations of setting. This hole is made use of in lowering the segments and in placing them in position. The method of setting the segments is as follows. A sheathing of pitch pine, $\frac{3}{8}$ in. or $\frac{1}{2}$ in. thick, is laid upon the upper surface of the wedging curb, to form the joint between it and the first course of tubbing; the breadth of this sheathing will be from 4 to 5 in. A course of tubbing is then set upon this bed all round the shaft, and fir sheathing, from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. thick, is placed between the joints, in the same manner as was required for the wedging curb. In order to close up the joints and to steady the tubbing in position, two strips of wood, 1 in. thick and from 4 in. to 6 in. broad, may be placed behind the vertical joints, between the tubbing and the rock; and a third strip, thinned off towards the end to form a wedge, driven down between them. The space between the tubbing and the rock is next filled in with loose rock from the excavation, or preferably, with good concrete. When the latter is used, it will be well to remove the wedging strips behind the vertical joints as the concrete is put in. Upon the top of this first course of tubbing, pine sheathing is laid to form the horizontal joints between the courses, and a second course is set up upon this, and fixed in position in the same manner as the first. The vertical joints of the second course must be over the middle of the segments forming the first course. These operations are repeated until the stone bracket supporting the wedging curb beneath the walling is reached. This rock is then cut away sufficiently to afford room for the tubbing, leaving a portion of the thickness to support the walling, and the tubbing completed up to the wedging curb. The joints have now to be tightened by wedging; beginning at the bottom, incisions are made with a broad chisel in the sheathing, and broad flat wedges are driven into the clefts thus made. These wedges are about 4 in. broad and $\frac{3}{8}$ in. thick at the head. When the joints have been filled with these, a square-pointed

2 A 8

steel tool is used to make fresh incisions, and spiles or square wedges of the same thickness are driven in wherever possible. The joints between the top course of tubbing and the wedging curb beneath the walling must also be tightly wedged. The plugging of the holes in the centre of each segment is also commenced from below. When the head of water is great, there is some difficulty in inserting the plug on account of the force with which the water issues. After the plug has been driven in as tightly as possible, the head is cleaved with a chisel, and an oak wedge driven into the cleft to increase the hold of the plug. Care must be exercised in plugging not to proceed too rapidly, because it is necessary that any air or gas that may be imprisoned behind the tubbing should be allowed to escape.

As the corroding action of water is very destructive to cast-iron tubbing, means must be adopted for protecting it. A thick coating of tar or of paint will be found sufficient in some situations. When the shaft is an upcast, and the mine is ventilated by furnace, or when there are engine fires underground, the destruction of the tubbing may proceed rapidly, and a lining of brick may be inserted; but such a lining renders it difficult to repair the tubbing or to stop a leaky joint, and when a lining of this nature is contemplated, the diameter of the excavation must be determined accordingly. Sometimes a lining of wood is put in to protect the tubbing, and should consist of deals 2 in. thick, having their edges properly bevelled to form close joints.

Cast-iron tubbing is more difficult to construct and to repair than wood tubbing; but it is far more durable under ordinary conditions, and it is capable of resisting a much greater pressure of water. The wood tubbing may be used with safety down to a depth of 100 yds.; but for greater depths iron tubbing is alone suitable. The thickness of cast-iron tubbing will be determined, as far as the exigencies of practice will allow, by the pressure which it will be required to sustain. The following formula gives the maximum thickness for segments not exceeding 2 ft. in depth, H being the head of water, and D the diameter of the shaft, in feet, and T the thickness of the plate, in inches;—

$$T = 0{\cdot}35 + 0{\cdot}00025\,HD.$$

In practice, the thickness is generally varied at every 25 ft.

There remains to be described another method of supporting the sides of the excavation during sinking to the stone head, adopted in the Lancashire districts, which dispenses with wood entirely, except for the walling curbs. This method is known as backcasing, and consists in employing bricks laid dry, in the place of the wood required in curbing.

The shaft is laid out with a diameter 20 in. greater than that required for the permanent walling, and carried down as far as the sides will stand safely. A walling curb, similar in construction to those described for the permanent walling, but of larger diameter, and smaller sectional dimensions, 9 in. × 3 in., is then laid upon a carefully levelled bed at the bottom of the excavation. A walling of dry bricks, one brick thick, is built up upon this curb to surface. The sinking is then resumed with a diameter equal to the inside of the curb, and continued down another 6 ft. At this depth, the sides of the excavation are shorn back at one part for a width equal to the length of one of the segments of the curb, and a segment of a new curb put in. Punch props will be required to support the curb beneath the walling at this point, from which the underlying bed has been removed. Upon this segment, a new length or course of walling is then built up, and tightly wedged to the first walling curb, so as to afford a good support to the latter. The wedges used for this purpose should be broad and thin, and preferably of fir. An adjoining portion of the sides of the excavation, equal in width to the first, is now shorn back, and a second segment of the curb laid and bolted to the first, and the walling carried up on this segment and joined by wedging to the upper curb. These operations are repeated until the whole of the curb has been laid, and the circle of walling put in. When this has been accomplished, the sinking is carried down in a line with the inside of the curb through another 6 ft., and the sides shorn back or walled as before upon a third curb. This mode of procedure is continued until the stone head is reached. If the work has been carefully executed, this backcasing will be nearly as strong as the permanent walling. When the stone head has been reached, the permanent walling is built up inside the backcasing. Thus, unlike the wooden curbing, the brick backcasing is left behind the permanent walling, whence its name. The support afforded by this system of backcasing is superior to that obtained from the wooden curbing.

In carrying a sinking down to the stone head through beds of quicksand, or loam saturated with water, an enormous pressure develops itself against the timbering. Instead of placing the curbs at intervals apart of 3 ft., it may be impossible to exceed 6 in., or it may even be necessary to place them in contact with one another. Also the strength of the curbs must be augmented by increasing their dimensions up to a sectional area of 6 in. × 6 in. The fluid character of the sand constitutes a very great difficulty in sinking, because the issue of the sand into the excavation occasions the falling in of the sides and the surface, besides the necessity which it creates of removing an indefinite quantity with the water to be lifted. When the water is under great pressure, this difficulty is insurmountable.

There are several methods of sinking through quicksand, but the general and most effective, when the sands exist near the surface, is by piling; that is, by driving planks close together vertically around the shaft, and supporting these internally with curbs. When this method of passing through the loose rock is to be adopted, the shaft must be laid out of a sufficiently large diameter to allow of the successive reductions which will have to be made at each course of piling. To do this accurately, it is necessary to know exactly the thickness of the beds, which must be ascertained from existing shafts in the locality, or if none be available for that purpose, by borings. It is seldom that the former source of information is sufficient, and preliminary borings may be regarded as generally necessary. As the curbs to be used are 6 in. × 6 in., and the pilings 3 in. thick, every fresh course of piling will diminish the diameter of the excavation by 18 in. With piles 15 ft. long, a fresh course will be required at about every 12 ft., so that the reduction of the

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